AMERICAN COLLEGE OF RADIOLOGY

PROCEEDINGS OF THE

SEVENTH CONFERENCE ON COMPUTER APPLICATIONS IN RADIOLOGY

BOSTON, MASSACHUSETTS
APRIL 25-28, 1982

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Prepared under the auspices of:
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PREFACE

This American College of Radiology sponsored conference on Computer Applications in Radiology was the seventh in a series which began in 1966. This conference included information on the use of computers in the management of Radiology department operations, microcomputer applications, teleradiology, computer based communication and certain aspects of digital and video imaging. Discussions of automated image analysis, which had been presented at earlier conferences, were conspicuous by their absence. Of special interest was the inclusion for the first time of discussions on the use of computers in Radiology billing.

The presentations in these proceedings comprise a resource of current information on these various topics.

For those who are interested in Radiology management systems, there is another excellent resource available from the American College of Radiology. This is Fascicle 9 in the "Planning Guide for Radiology Installations" series. The title of this fascicle is "Computer Information Systems." It includes ten chapters on various aspects of information systems, presented from the perspective of what has been accomplished and should be included in such systems. A chapter on installing, managing and evaluating such systems presents

much valuable information. This fascicle presents an excellent overview of Radiology management systems and is quite current, as it was released in November of 1981. The authors are members of the ACR Committee on Computers.

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LOCALIZATION BY COMPUTED TOMOGRAPHY

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This research was supported in part by funding from the Research Council of the University of Missouri, Columbia School of Medicine.

ABSTRACT: A method of reformating CT images to allow easy localization of lesions is described. It retains patient anatomic information and superimposes the location of the lesion obtained interactively from the CT images.

We would like to discuss the process of localizing a lesion or mass in a patient. This is important when further treatment or care of the patient depends on accurate position information. The problem is to localize the lesion quickly and accurately. A related problem is to put the information in a form that is easily transfered to the next procedure. The requirements of a localization method are first that the lesion be seen in its entirety and secondly that there is an easy reference system between the detection method and the patient.

Over the years several methods have developed to localize a lesion. The easiest and most straightforward is physical examination. The physician feels the lesion and knows where it is. The major problems with this have been that it is not applicable to all lesions and frequently adjacent, sensitive organs cannot be identified except by guessing where they should be. Plain radiography has been used and depends on radiographic anatomy or abnormalities to detect and localize the lesion. Adding contrast material has improved this and frequently allows the lesion itself to be seen. To improve the accuracy of these

further, grids and various localization devices have been used. Most recently, methods using CT information have been used, primarily in complex CT-RT treatment planning systems. Many devices have been used in CT to localize an object (1,2,3). One is made of various lengths of radiopaque material, usually angiographic catheter material embedded in plastic or, as here, stuck together with tape to be more flexible. This gives a step function when scanned, counting the number of tubes or lines tells you where you are on a plain radiograph. A continuously varying device is a rigid triangle made of some plastic easily seen on CT. When scanned this will show up as two dots and measuring the distance between the dots will tell one where that plane is.

There may be several limitations to any one of these methods. The method may be time consuming. If information from an original diagnostic examination can be used for localization, an extra procedure may be unnecessary. It may be of limited accuracy. This becomes increasingly important with smaller lesions. For most of the previously listed methods only one point is identified at a time. If the points or information produced by localization are not easily transferred to skin marks or other external landmarks, the subsequent procedure may have to be done with the localization method close at hand. For CT this implies tying up an entire room, sometimes unnecessarily. Finally the need for very fine resolution in localization will be critical in small lesions, as well as indicating where normal structures that should be avoided are. While not all these limitations are answered by the method to be described, we think that most are.

The concept is to retain the anatomic information from the CT scans in a convenient form, such as a scanogram image and add to it the locatization information from the CT slices about the extent of the lesion (Fig. 1). Let us look at three cases. First

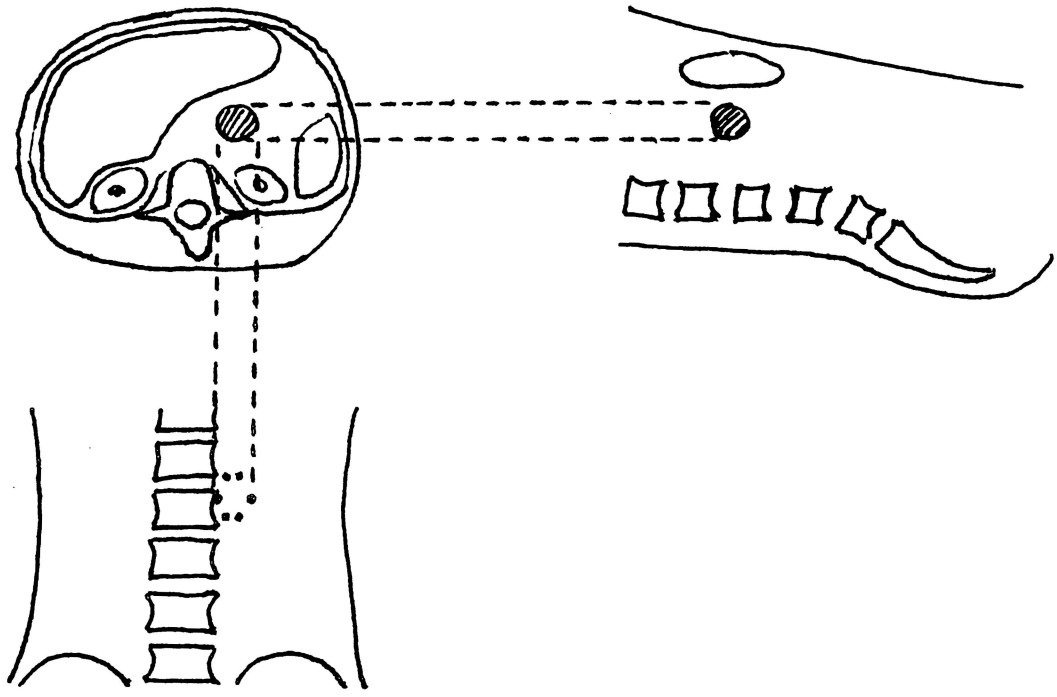


Figure 1. Reformating of a CT scan to form a line which becomes a part of a larger projection in A-P or lateral view.

is a 53 year old man with dull, boring back pain. We can see on the CT image, the pancreas with a fairly obvious mass, which turned out to be a carcinoma and needed further therapy. By building up the scanogram from the CT slice data, we can display the anatomy with the lesion localized. The columns of CT data are summed and displayed on an edge. When the tumor is in a slice, its extent laterally or anteriorly and posteriorly are identified. This may be done with any interactive/cursor controlled device; we used a Graf-pen/television interactive system (4). As the image is built up, the location of the tumor becomes evident in what amounts to an A-P radiograph. (The last line includes the iliac crest, so places the image in the abdomen with this additional anatomy known.) Similarly if rows are summed instead of columns a lateral image is obtained. And ultimately if we are able to interface with our CT machine software, we may overlay the

position data on the electronic radiograph, the scanogram obtained by this CT machine and so many others. The scanogram has much better resolution than our built-up A-P view. The second case is a 32 year old woman with seizures. On the CT scan the source of the seizures seemed to be due to a lesion in the medial part of the temporal lobe. From the original diagnostic scans the lesion was localized in A-P and lateral projections quite easily, by our method. The third case is a 57 year old male with a known abdominal mass, where the extent of the lesion can be depicted in the A-P and lateral projections and overlayed on the scanogram.

This localization data will typically be used to plan a biopsy of the lesion, to plan a surgical approach, or to plan radiation treatment. There are many potential errors in this and any other localization method. When using CT, one always has to consider partial volume artifact which from right to left is usually minimal, but may be signifigant in the cephalo-caudal direction depending on the slice width used. Mis-registration of anatomy and inconsistent positioning are errors that must be eliminated by care in doing the original CT procedure. Positioning the patient obliquely in the gantry and several different degrees of inspiration are probably the most signifigant of this error. Finally, errors in one's ability to position the dot for the edge of the lesion may cause errors for the subsequent procedure. And even though we see the macroscopic limits of the lesion on CT, the microscopic edge (pseudopods, etc.) of an infiltrating lesion may not be seen at all.

We have described a method of localization by computed tomography that is simple, retains information about patient anatomy and the lesion, does not require an addition patient examination, and can be easily used for subsequent biopsy or therapeutic planning. While it is not fully developed it has promise of simplifying some of the procedures currently used.

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SOME COMPUTATIONAL CONSIDERATIONS IN DUAL-ENERGY SCANNING

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ABSTRACT

Dual-energy scanning in digital radiography has been demonstrated to be a useful image enhancement technique. The efficiency of the technique and quality of the resultant images depend on the model chosen during the surface fitting procedure. This paper compares three different models on their efficiency and the degree of enhancement in the resultant images. The comparison is based on the computational time required for a particular model to decompose a high energy and a low energy image into their aluminum-equivalent and plastic-equivalent images. The resultant images of various phantoms obtained from these three different models are compared and discussed.

I. INTRODUCTION

Dual-energy scanning in digital radiography has been shown to be a good image enhancement technique[1,2,3]. This procedure consists of the following three steps: (1) step wedges assembled with various combination of aluminum and plastic thin layers are scanned at two energies, (2) an object of interest is scanned under the same conditions at the two same energies, and (3) plastic-equivalent and aluminum-equivalent images of the object can be derived from (1) and (2) using a surface fitting technique which would enhance the contrast between materials within the object.

The surface fitting required in step (3) is quite computa-

tional involved and the procedure of the fitting has not been fully explored. The purpose of this paper is to study the computational efficiency and the quality of resultant images when various surface fitting models are utilized. Experiments were performed with the Pilot Scan of the Picker SD600 CT scanner using 80kVp and 140kVp on various phantoms. No modification was necessary to the scanner for these experiments except that different filters were placed at the detector site for the high and the low energy scan, respectively.

The method and procedure in dual-energy scanning will be presented in Section 2. Three surface fitting models: linear, cross-product and full quadratic, will be discussed in the computational procedure section. Plastic-equivalent and aluminum-equivalent images of various phantoms obtained by using the three models will be presented and discussed in the last two sections.

II. METHOD AND PROCEDURE IN DUAL ENERGY SCANNING

2.1 Dual-Energy Scanning[4]

The theory of dual-energy scanning using plastic and aluminum wedges for calibration[5,6] can be summarized by the following two equations:

$$\ln (I/I_o)_h = \ln \left\{ \int S_h(E) e^{-[A_{PL}\mu_{PL}(E) + A_{AL}\mu_{AL}(E)]} dE \right\} \quad (1)$$

and

$$\ln (I/I_o)_\ell = \ln \left\{ \int S_\ell(E) e^{-[A_{PL}\mu_{PL}(E) + A_{AL}\mu_{AL}(E)]} \, dE \right\} \quad (2)$$

where I_o is the intensity of the incident beam,

I is the transmitted intensity measured at the detector,

$S_h(E)$, $S_\ell(E)$ are the x-ray spectra produced by an x-ray tube operated at potential V_{high} and V_{low} respectively,

A_{PL}, A_{AL} are the plastic and the aluminum-equivalent thickness respectively,

$\mu_{PL}(E)$, $\mu_{AL}(E)$ are the total linear attenuation coefficients of plastic and aluminum respectively, and

the subscripts h and ℓ represent high and low energies.

If an object of interest is scanned two times one with V_{high} and the other V_{low}, then the values $\ln(I/I_o)_h$ and $\ln(I/I_o)_\ell$ for each pixel in the high and low energy images are known. A_{PL} and A_{AL} can then be solved from Eqs. (1) and (2). In practice, the right-hand side of Eqs. (1) and (2) are approximated by two finite power series in A_{PL} and A_{AL} as follows:[2,5]

$$\ln(I/I_o)_h = a_o + a_1 A_{AL} + a_2 A_{PL} + a_3 A_{AL} A_{PL} + a_4 A_{AL}^2 + a_5 A_{PL}^2 \quad (3)$$

and

$$\ln(I/I_o)_\ell = b_o + b_1 A_{AL} + b_2 A_{PL} + b_3 A_{AL} A_{PL} + b_4 A_{AL}^2 + b_5 A_{PL}^2 . \quad (4)$$

The values for the constants a_i and b_i are determined from the calibration procedure.

2.2 Equipment

The Pilot Scan® of the Picker Synerview® SD600 CT Scanner was used for the experiment. The Pilot Scan® produces a P-A view 256 x 256 digital image with pixel values (DR numbers) ranging from -1000 to 1000. In this study the x-ray potential has adjusted to 80kVp for low energy scan (80mA) and 140kVp for high energy scan (50mA). A Lanex cassette was placed in the incident beam for the high potential scan to selectively attenuate the tungsten characteristic lines. Four layers of a $CaWO_4$ conversion screen were placed in the incident beam for the low potential scan to cut off spectral components above the tungsten characteristic lines. The result was a somewhat heightened material (Z) dependence because of the decreased overlap between the high and low spectra. Subsequent numerical calculations for dual-energy images were performed using the scanner's two Interdata 7/32 minicomputers with the raw data directly from the detector readings. Resultant images were then converted to the arbitrary DR scale used by the scanner for display.

2.3 Calibration Procedure

An aluminum step wedge with eight steps of 1/8" 1100 aluminum (ρ=2.70g/cm^3) and a Lucite® step wedge with seventeen steps of 1/4" each (ρ=1.19g/cm^3) were used for calibration.

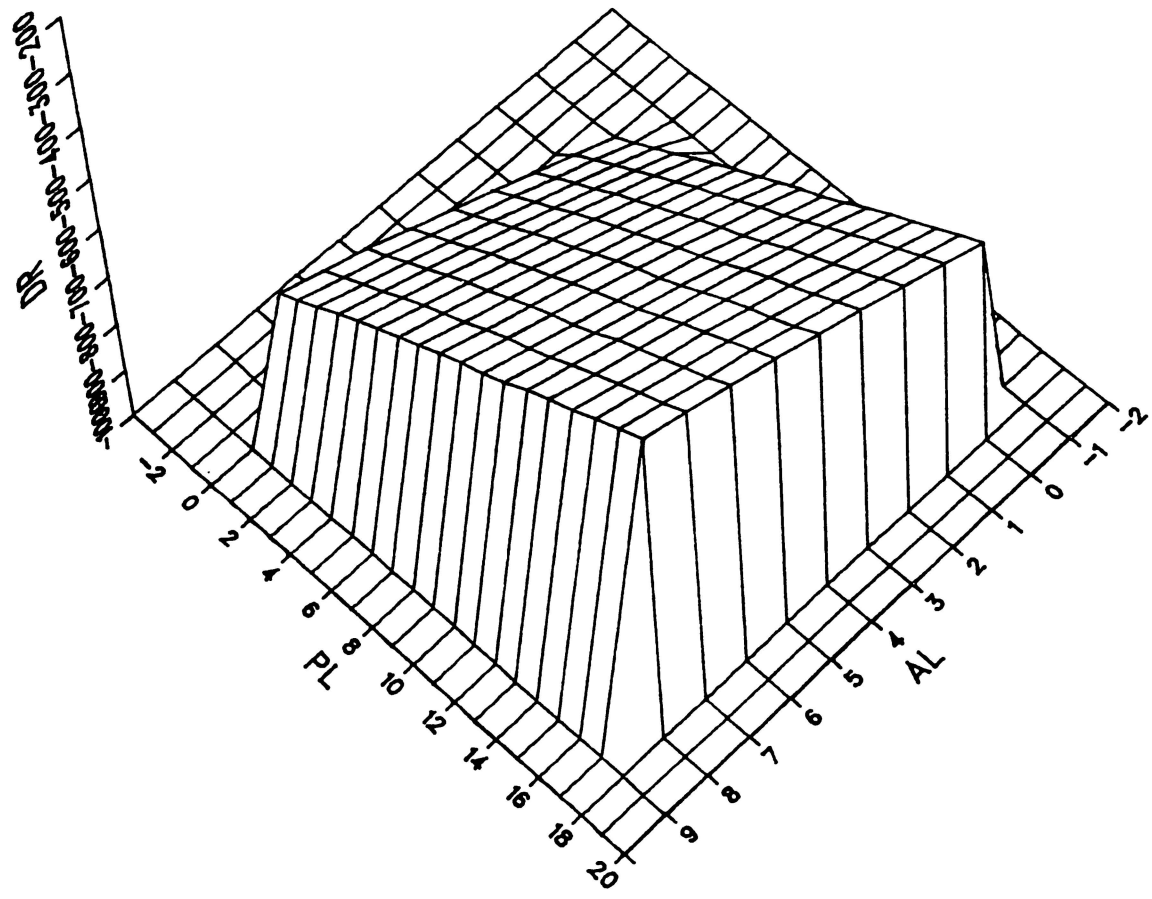


Figure 1 Data obtained by using the high energy scan on the calibration wedges.

These two materials are commonly referred to as the basis materials. All possible combinations of aluminum and Lucite® steps were scanned with filtered high and low energy spectra as described in Section 2.2. Two surfaces, one for the high and the other low energy spectrum were generated as depicted in Figures 1 and 2. These two surfaces were used to obtain the constants a_i and b_i in Eqs. (3) and (4).

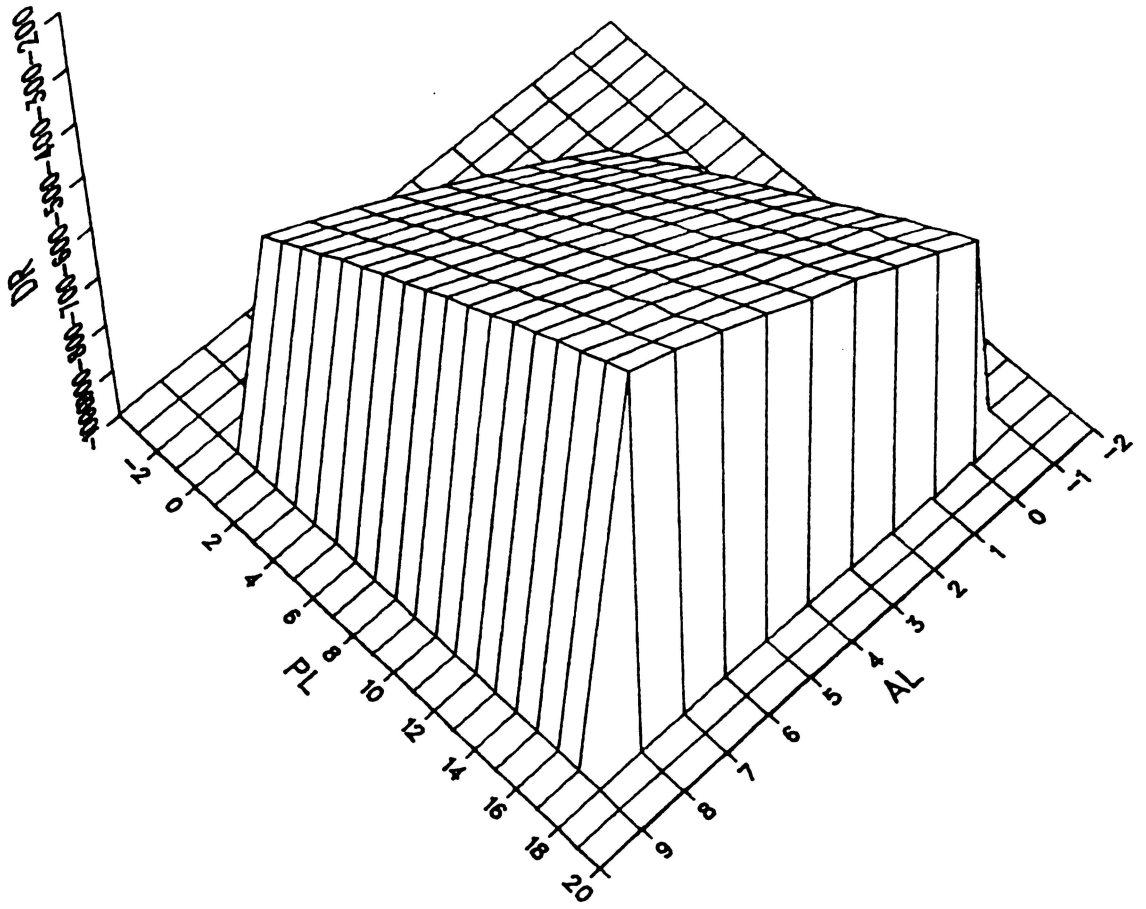


Figure 2 Data obtained by using the low energy scan on the calibration wedges.

III. COMPUTATIONAL PROCEDURE

A_{AL} and A_{PL} can be obtained by solving Eqs. (3) and (4). The collection of all A_{AL} and A_{PL} form the aluminum-equivalent and the plastic-equivalent image respectively. In this section three models will be discussed in solving these two equations. Both the integer arithmetic and the floating arithmetic method will be considered for each model.

3.1 Linear Model

If the non-linear terms are ignored from Eqs. (3) and (4), then

$$H \equiv (I/I_o)_h = a_o + a_1 * A_{AL} + a_2 * A_{PL} \quad (5)$$

$$L \equiv (I/I_o)_\ell = b_o + b_1 * A_{AL} + b_2 * A_{PL} \quad (6)$$

The surface fitting routine using calibration data described in 2.3 gives the following result:

$a_o = -985.63281352$	$b_o = -977.98356075$
$a_1 = 31.10833333$	$b_1 = 45.98240741$
$a_2 = 21.6581814$	$b_2 = 24.41738333$
$R^2_H = 0.999068$	$R^2_L = 0.998322$

where R^2_H and R^2_L are the squares of the correlation coefficients.

In order to speed up the calculation, integer*4 arithmetic was used. The resultant equations for A_{AL} and A_{PL} after proper scaling have the forms:

$$A_{AL} = [(-103327)H + (91651)L + (-12209450)]/10000 \quad (7)$$

$$A_{PL} = [(194584)H + (-131641)L + (63045381)]/10000 \quad (8)$$

3.2 The Cross-Product Model

If the A^2_{AL} and A^2_{PL} terms are ignored from Eqs. (3), (4) then

$$H \equiv (I/I_o)_h = a_o + a_1 A_{AL} + a_2 A_{PL} + a_3 A_{AL} \cdot A_{PL} \qquad (9)$$

$$L \equiv (I/I_o)_\ell = b_o + b_1 A_{AL} + b_2 A_{PL} + b_3 A_{AL} \cdot A_{PL} \qquad (10)$$

The surface fitting routine using calibration data described in 2.3 gives

$a_o = -993.05211176$	$b_o = -990.33034438$
$a_1 = 32.96315789$	$b_1 = 49.06910331$
$a_2 = 22.53104002$	$b_2 = 25.86994611$
$a_3 = -0.21821465$	$b_3 = -0.36314069$
$R^2_H = 0.999515$	$R^2_L = 0.999106$

After scaling, Eqs. (9) and (10) can be rewritten as:

$$A_{AL} = \frac{-[(225310)L + (-258699)H + (-33770320)]}{(-22)L + (36)H + (-10831) - A_{AL}} \qquad (11)$$

$$A_{PL} = \frac{(10000)H + (9930521) + (-3296)A_{AL}}{[2253 + (218)A_{AL}/100]} \qquad (12)$$

which can be solved using an iteration procedure.

3.3 Quadratic Model

The quadratic model includes all terms in Eqs. (3) and (4). In this case, the Newton-Raphson iteration technique is used for solving A_{AL} and A_{PL}. The initial guess comes from the solution of the linear model (Eqs. (5), (6)).

The fitting routine gives the following results for the coefficients:

Table 1

Computational Efficiency Among the Three Models

(Interdata 7/32 Minicomputer, Standard FORTRAN)

TIME REQUIRED / MODEL	(PL-Equivalent and AL-Equivalent Images, 256 x 256) Integer Arithmetic	Floating Arithmetic
Linear	53 sec.	4 min.
Cross-Product	80 sec.	10 min.
Quadratic		30 min.

$a_0 = -999.51483844$ $b_0 = -1002.10339654$

$a_1 = 35.66108959$ $b_1 = 54.47218172$

$a_2 = 23.77421741$ $b_2 = 27.92099387$

$a_3 = -0.21821465$ $b_3 = -0.36314069$

$a_4 = -0.33724146$ $b_4 = -0.6753848$

$a_5 = -0.07312808$ $b_5 = -0.12064987$

$R^2_H = 0.99988$ $R^2_L = 0.9999$

Table 1 gives a comparison among these three models on their efficiency. The resultant images will be shown in the next section.

IV. RESULTS

Two phantoms were used for the experiment: (1) The Humanoid Systems' Lung-Chest Phantom, and (2) A wedge-shaped Lucite®

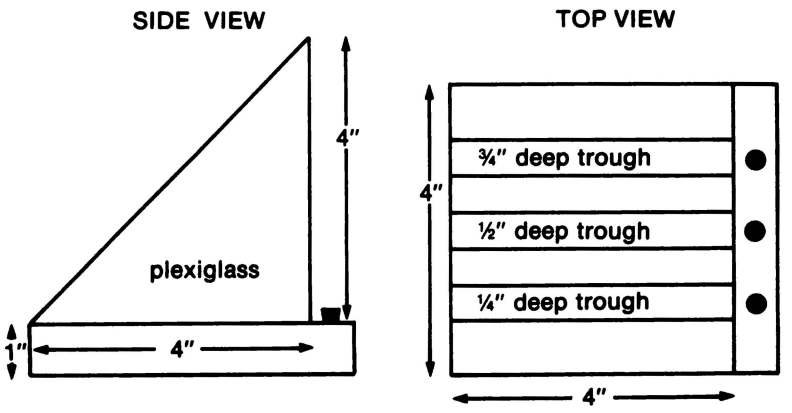


Figure 3 Side and top views of the Lucite® Phantom. The troughs were filled with diluted iodine solution (100 ml H_2O to 2.87 ml of 141 mg/ml iodine solution).

phantom. Figure 3 shows the side and top views of the Lucite® phantom with proper dimensions. There are three troughs of 1/4", 1/2", and 3/4" depth at the bottom of the phantom and these were filled with diluted iodine solution of the same strength (100ml H_2O to 2.87ml of 141mg/ml Iodine solution), giving 2.5, 5, and 7.5 mg/cm2 of iodine.

Figure 4 shows the high and low energy images of the Lucite® phantom with tracings showing the plastic wedge and the iodine troughs. Figure 5 shows the enhancement of the iodine in the AL-equivalent and PL-equivalent images. Figure 6 depicts the high and low energy images of the Humanoid System's Lung-Chest Phantom and the selective soft tissue image derived from the AL-equivalent and the PL-equivalent image. Figure 7 shows the

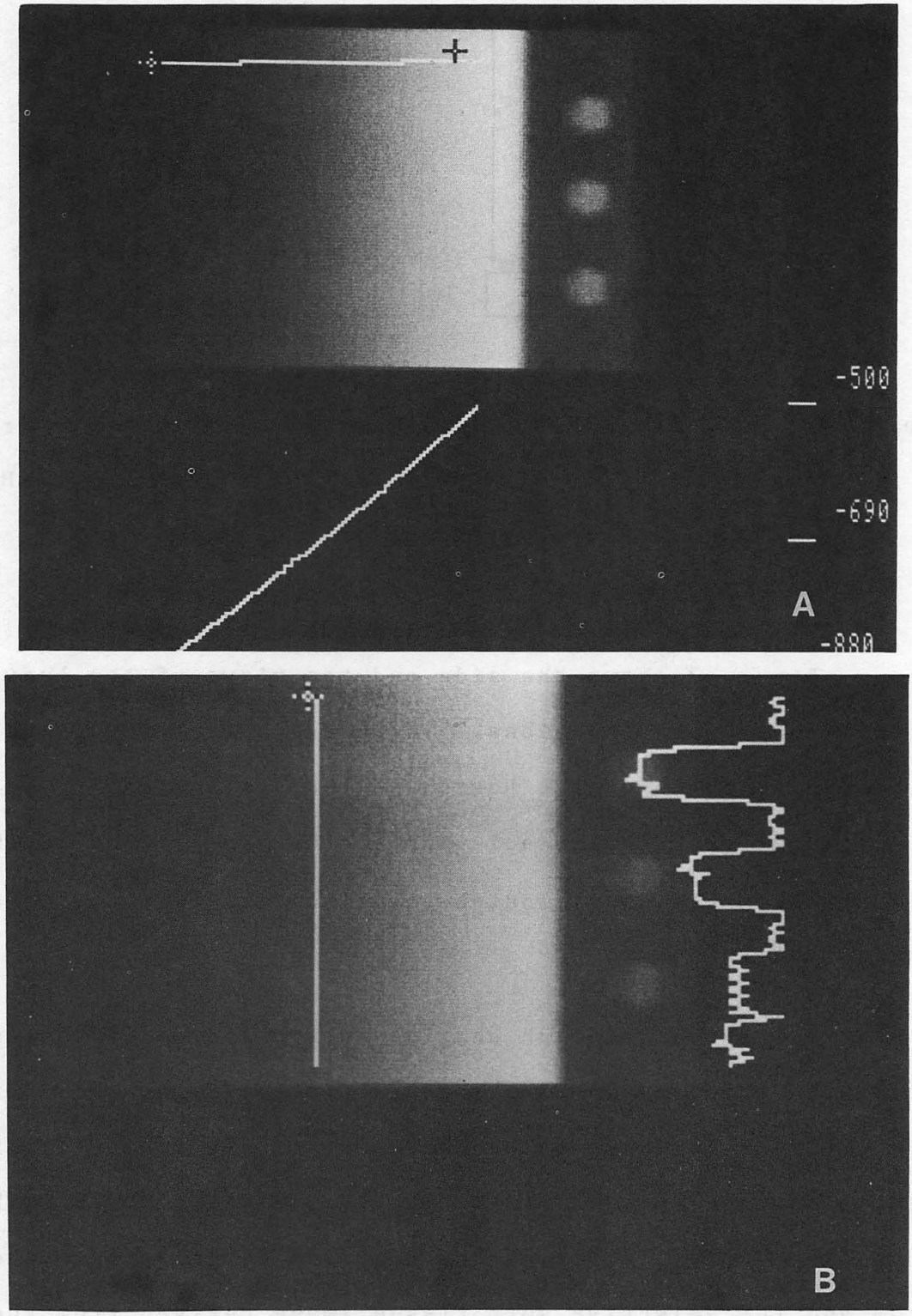


Figure 4 Digital radiographical images of the Lucite® Phantom with tracings.

a,b: low energy (80 kVp)

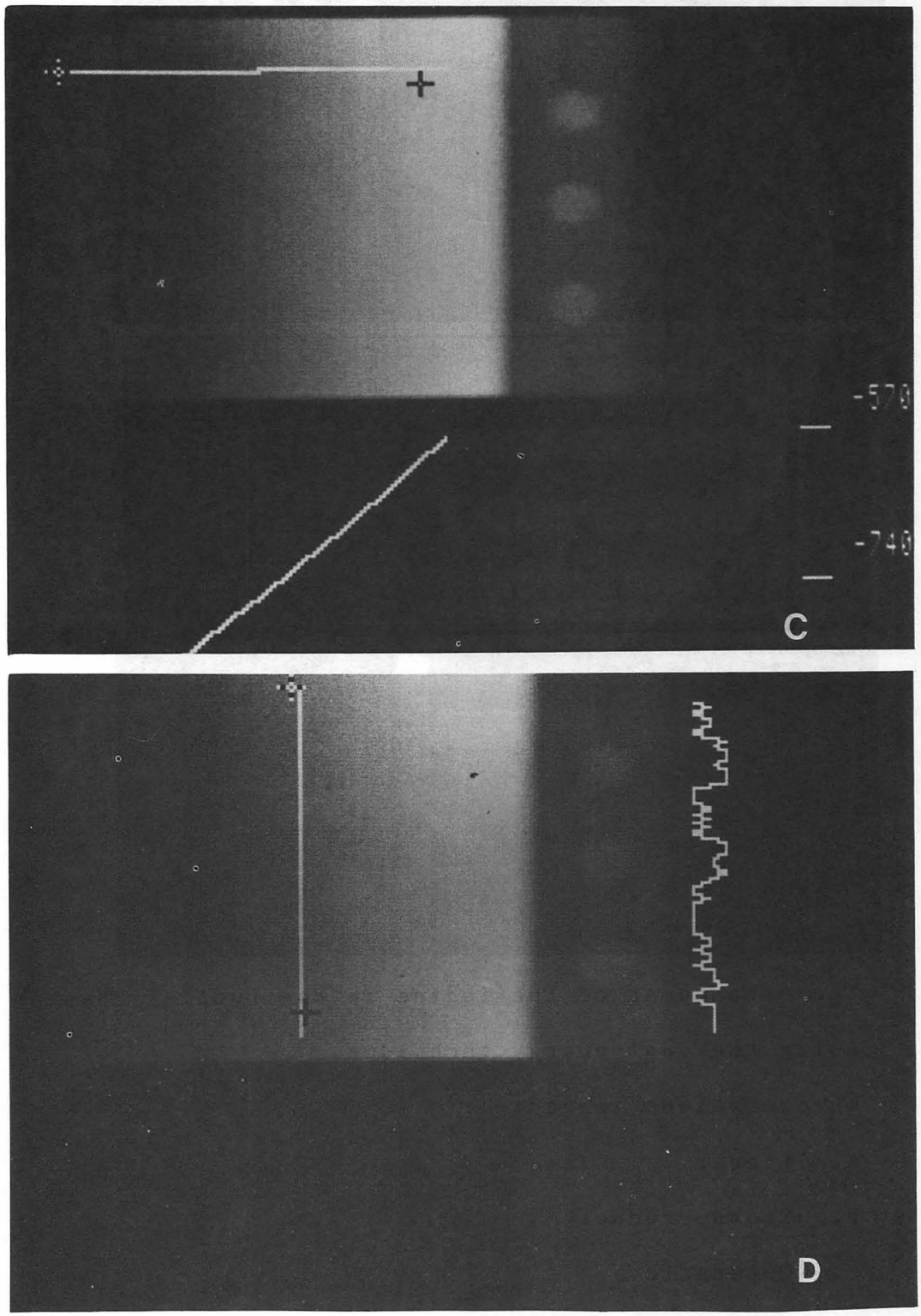


Figure 4 Digital radiographical images of the Lucite® Phantom with tracings.

c,d: high energy (140 kVp)

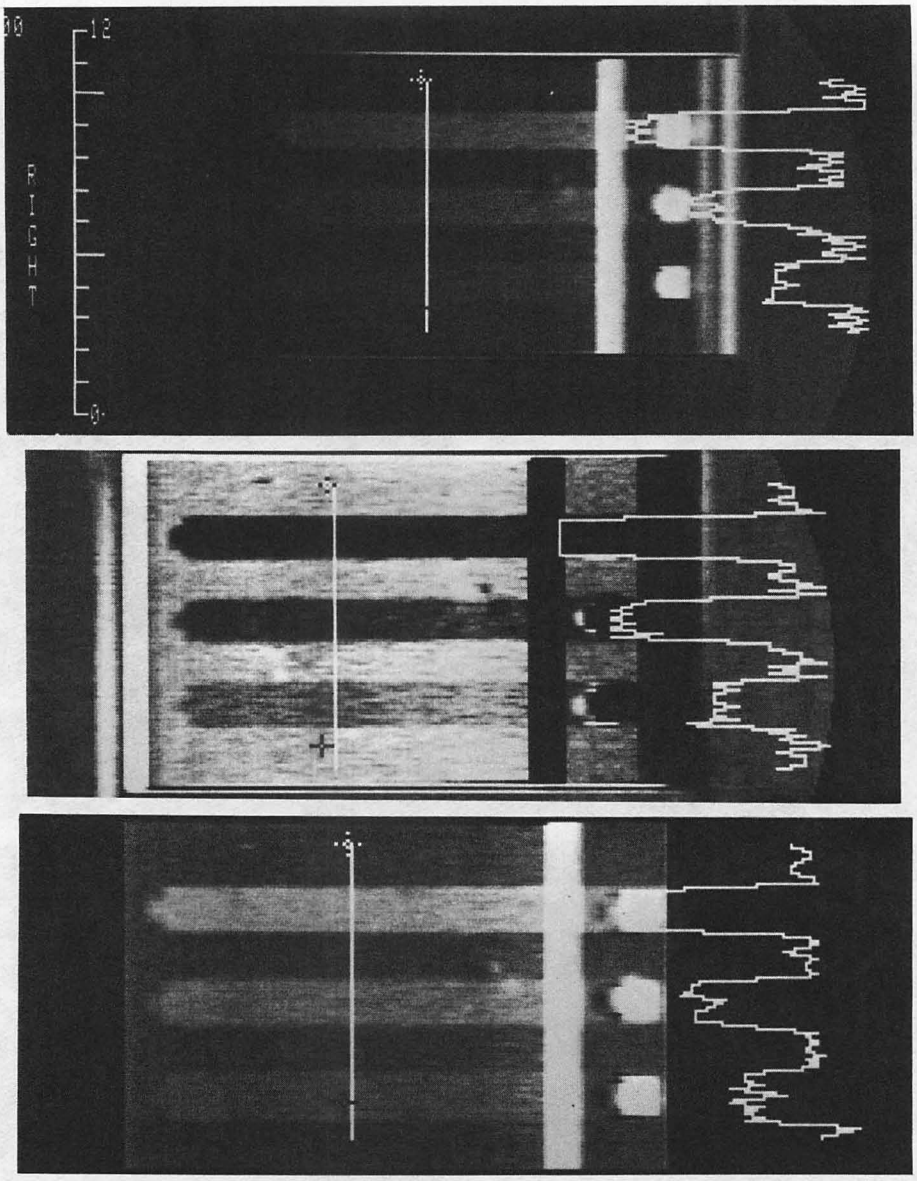


Figure 5 The enhancemnt of the iodine in the Lucite® Phantom using the dual-energy technique.

AL-equivalent Images:

a. Linear

b. Cross-Product

c. Quadratic

The tracings through the three troughs demonstrate the degree of the enhancement, compare these tracings with those shown in Fig. 4.

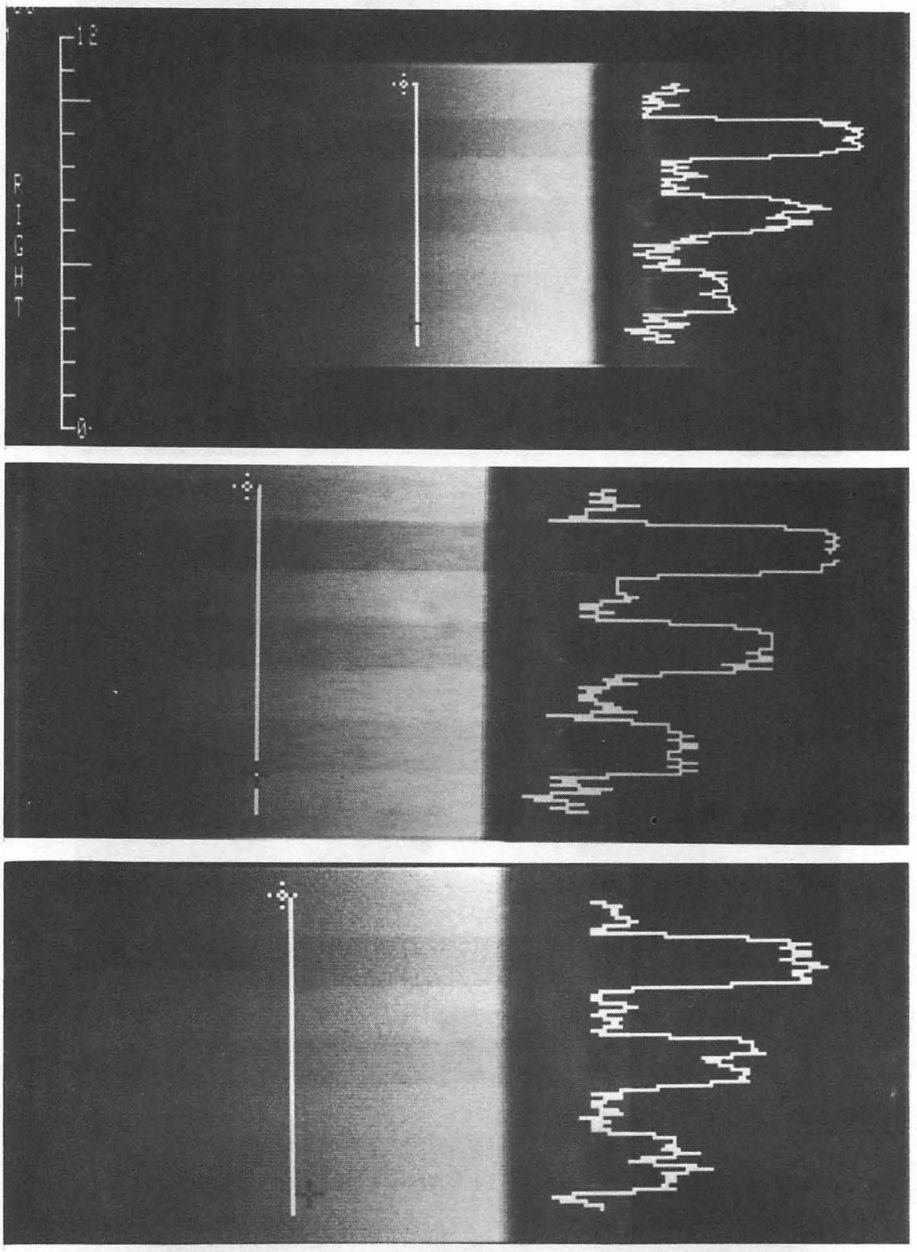


Figure 5 The enhancemnt of the iodine in the Lucite® Phantom using the dual-energy technique.

PL-equivalent Images:

d. Linear

e. Cross-Product

f. Quadratic

The tracings through the three troughs demonstrate the degree of the enhancement, compare these tracings with those shown in Fig. 4.

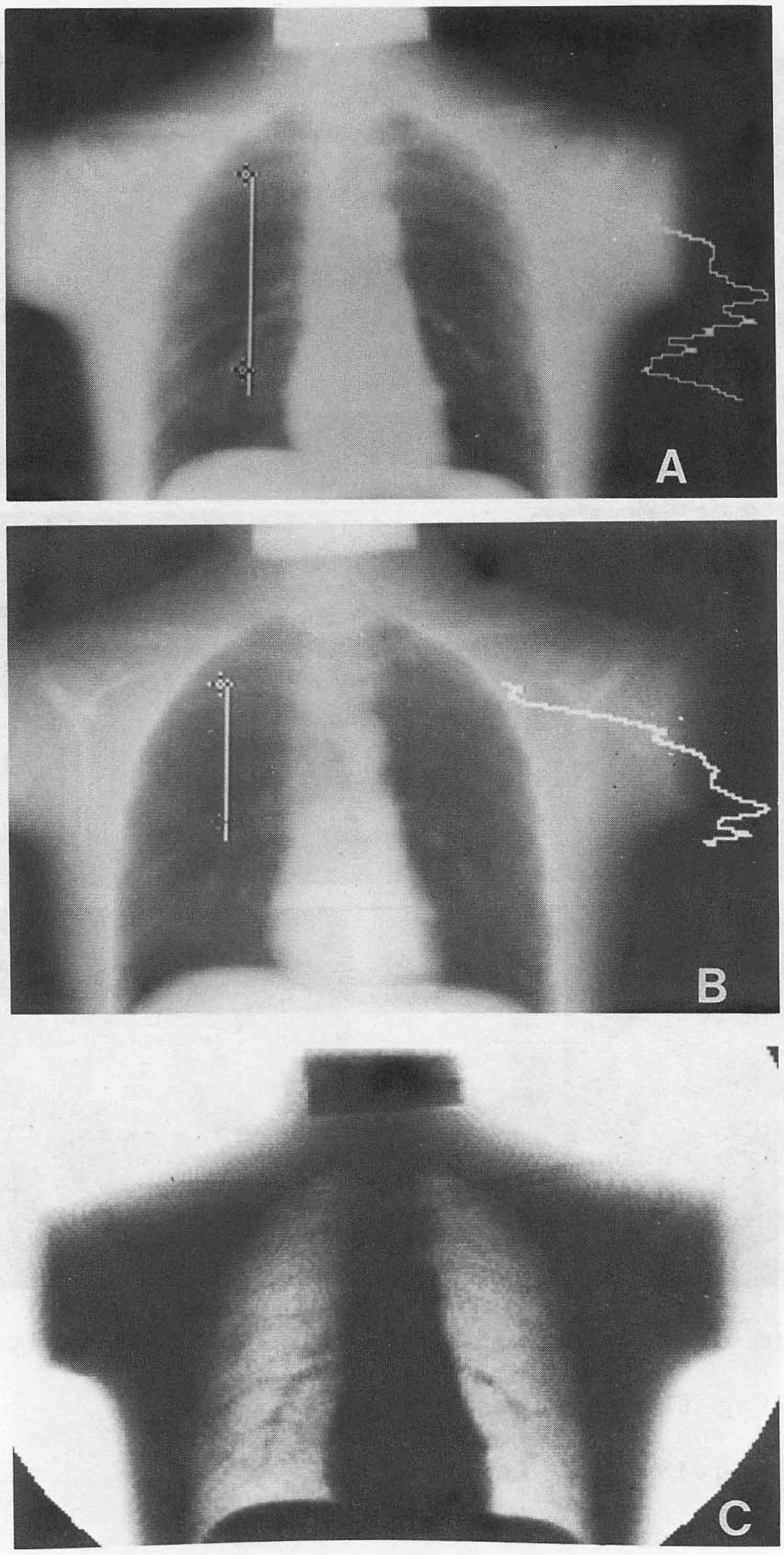


Figure 6 The Humanoid System's Lung-Chest Phantom.

a. Low energy scan

b. High energy scan

c. Selective soft tissue image derived from the AL-equivalent and the PL-equivalent image.

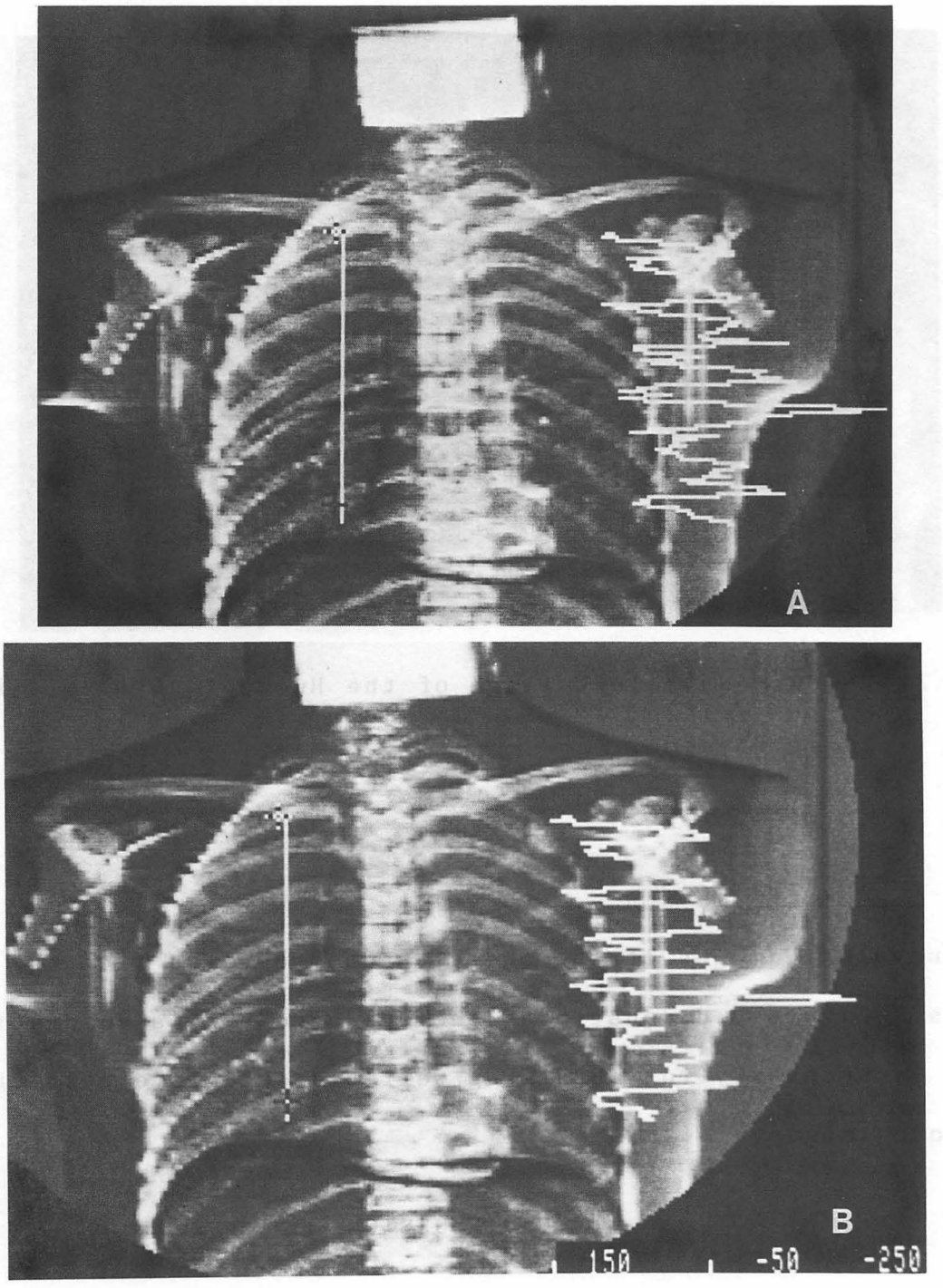


Figure 7 The AL-equivalent image of the Humanoid System's Lung-Chest Phantom.

a. Linear

b. Cross-Product

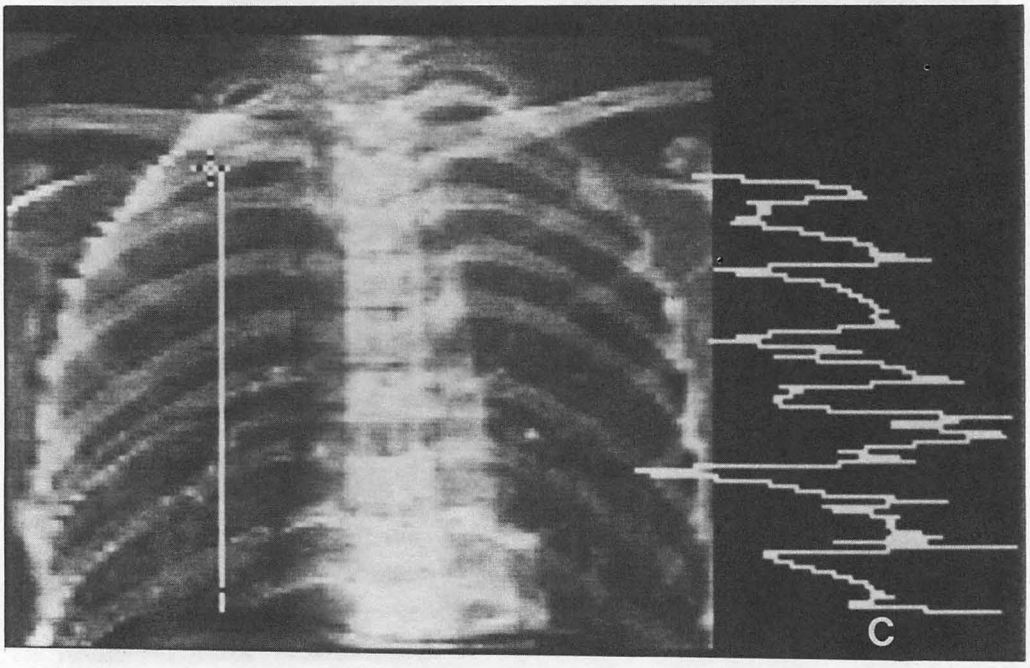


Figure 7 The AL-equivalent image of the Humanoid System's Lung-Chest Phantom.

c. Quadratic

AL-equivalent images of the chest phantom derived from the three models. Figure 8 demonstrates the evidence that a quadratic model is necessary for obtaining reliable selective soft tissue and bone images.

V. DISCUSSION

5.1 The Best Model

If an object of interest consists of two arbitrary materials M_1 and M_2, and if AL and PL are the two basis materials, (see 2.3), then

$$A_{AL} = k_1 L_1 + k_2 L_2 \quad (13)$$

$$A_{PL} = k_3 L_1 + k_4 L_2 \quad (14)$$

where k_1, k_2, k_3, k_4 are constants and L_1 and L_2 are the thickness of M_1 and M_2, respectively.

If it happens that M_1 is the plastic (PL), then $k_1 = 0$, $k_3 = 1$ and Eqs. (13) and (14) become

$$A_{AL} = k_2 L_2 \quad (15)$$

$$A_{PL} = L_1 + k_4 L_2 \quad (16)$$

which can be used as a guideline of acceptance for a model.

Thus in the Lucite® Phantom study, all the tracings in the AL-equivalent images shown in Figs. 8a,b,c are over a region of the plastic only, therefore $L_2 = 0$ or $A_{AL} = 0$. Therefore, Eq. (15) implies that all the tracings should be horizontal lines. Among the three models only the quadratic model behaves as it should be while cross-product and linear models are either over-estimated or under-estimated.

Also, the tracings in the PL-equivalent images shown in Figs. 8d,e,f are also over a region of plastic only, therefore $L_2 = 0$. Eq. (16) imples that $A_{PL} = L_1$ which is the thickness of plastic in the phantom. Only the tracing in the quadratic model behaves like a straight line. Based on these two arguments, we

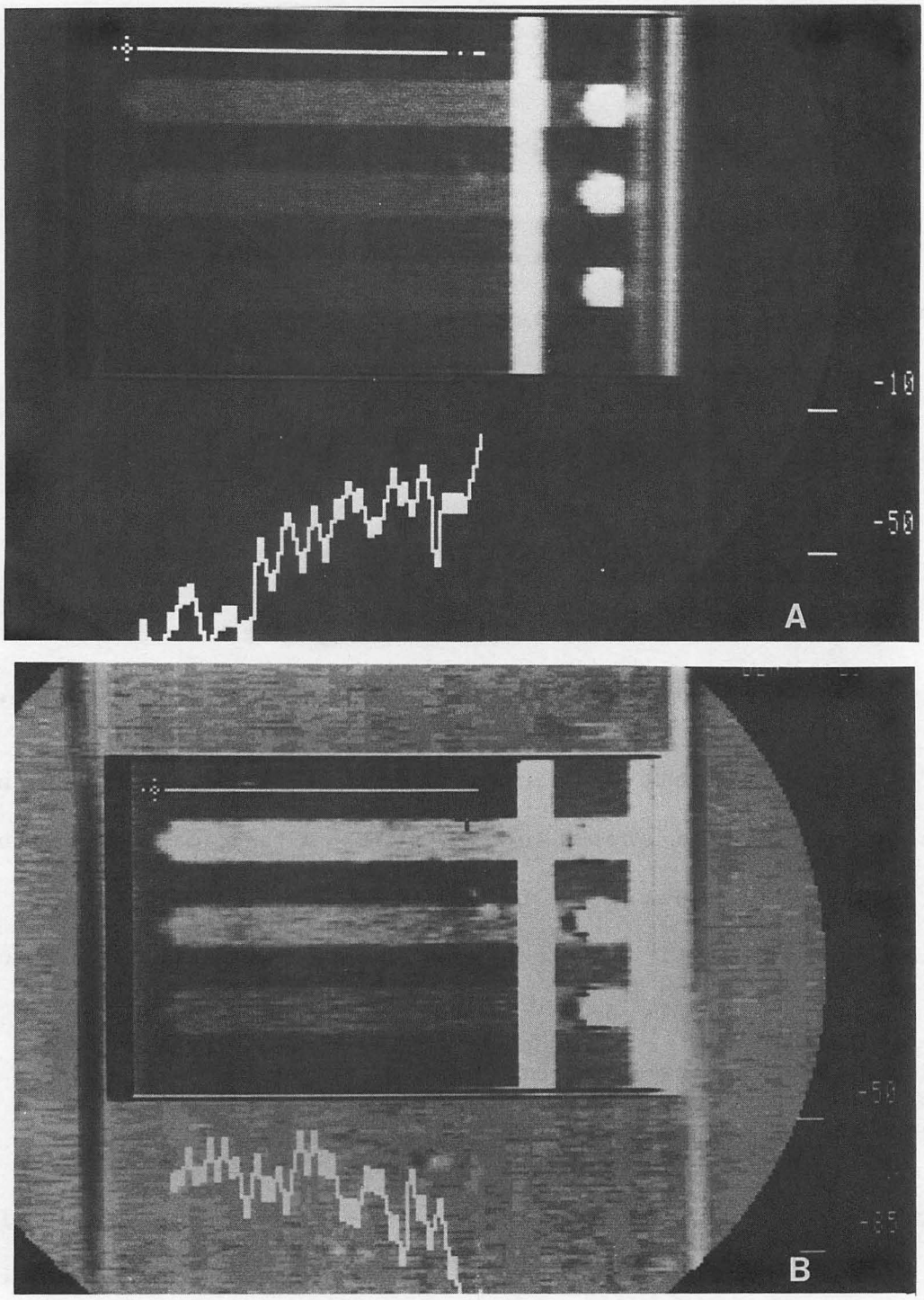


Figure 8 Evidences demonstrating the Quadratic is the best model.

AL-equivalent image:

a. Linear : tracing is not horizontal

b. Cross-Product: tracing is not horizontal

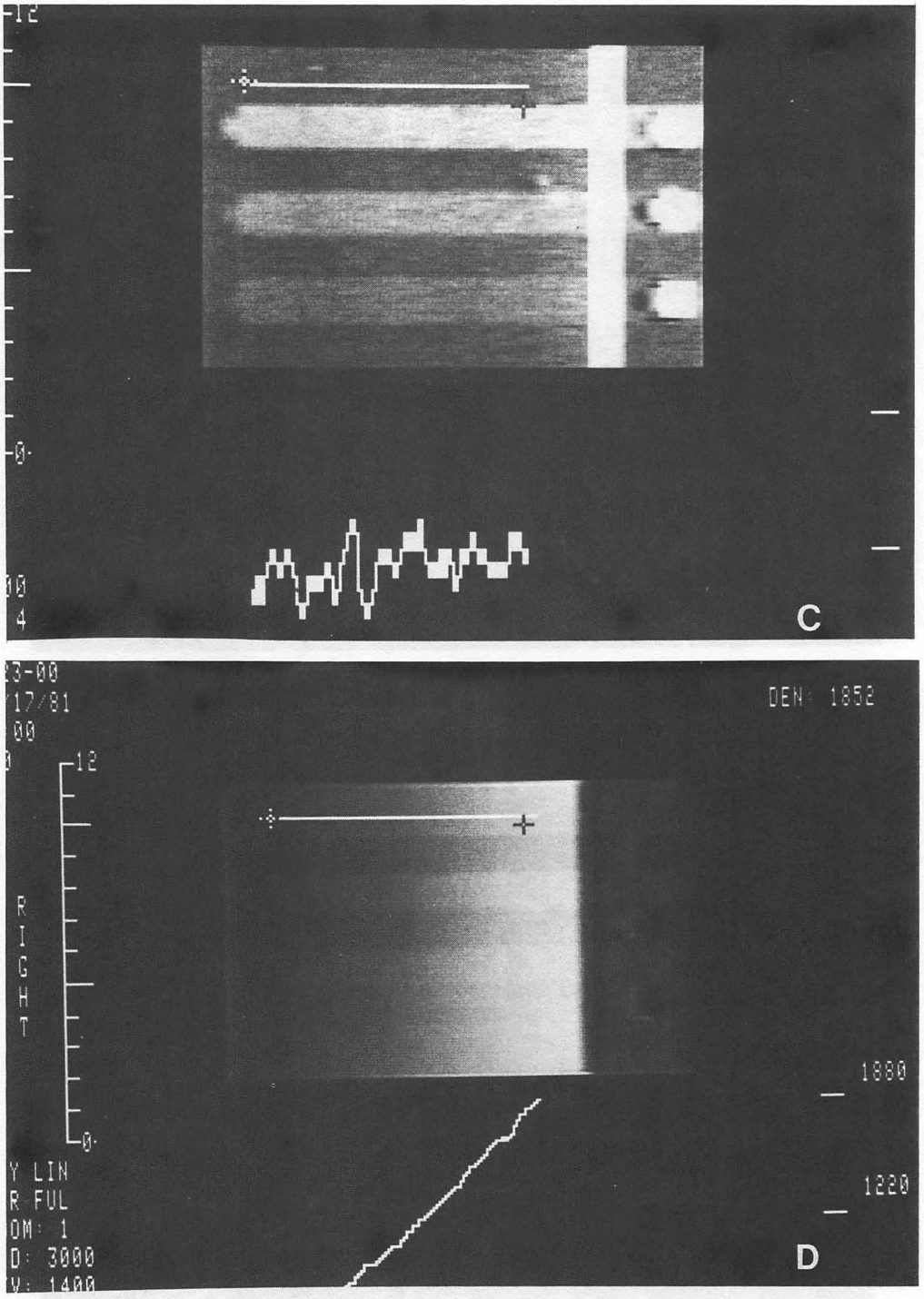


Figure 8 Evidences demonstrating the Quadratic is the best model.

AL-equivalent image:

c. Quadratic : tracing is horizontal

PL-equivalent image:

d. Linear : tracing is not quite a straight line

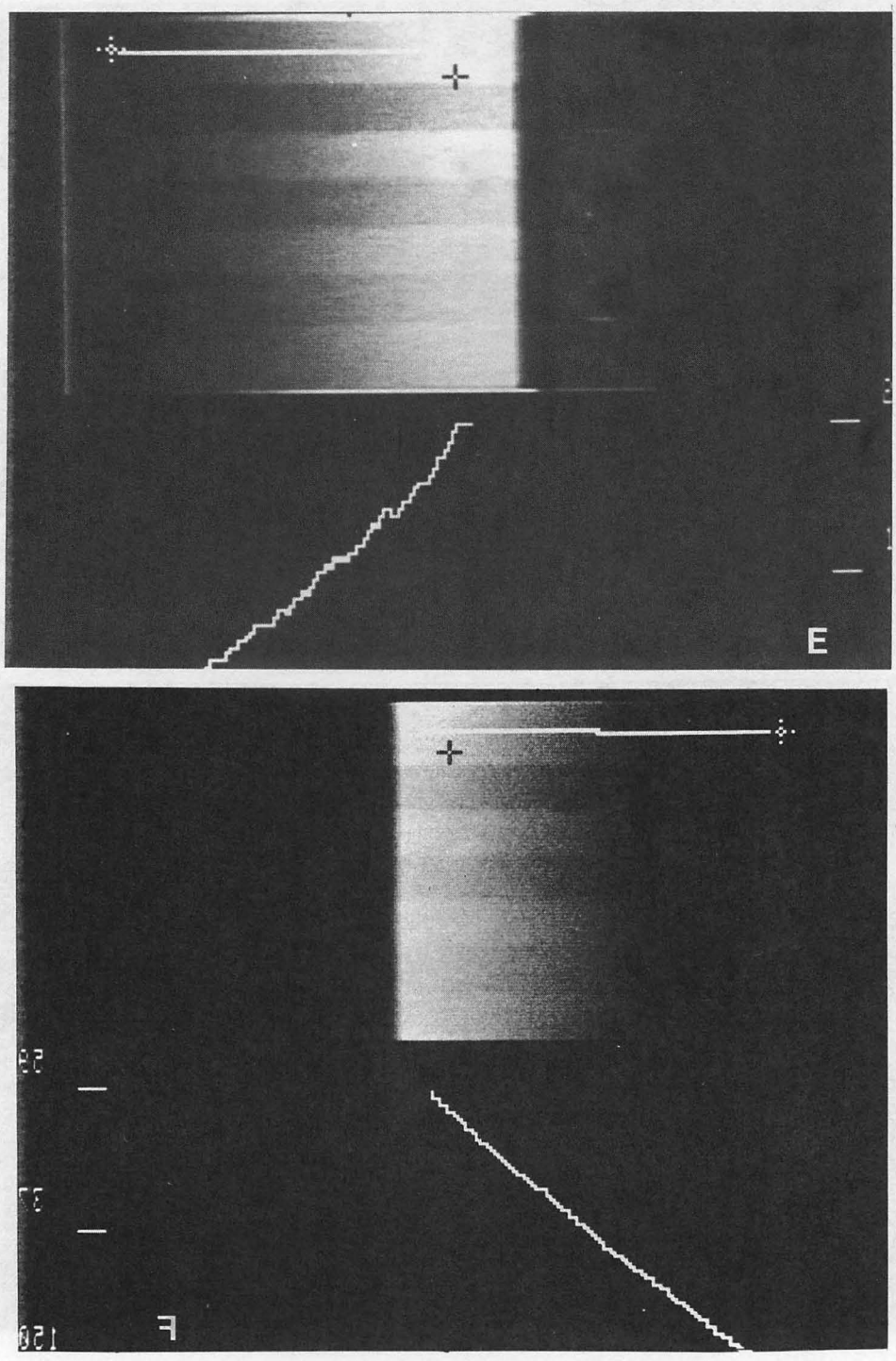


Figure 8 Evidences demonstrating the Quadratic is the best model.

PL-equivalent image:

e. Cross-Product: tracing is not quite a straight line

f. Quadratic : tracing is a straight line

conclude that a quadratic model is the best among the three models.

5.2 Use of the Dual-Energy as an Image Enhancement

Either the linear or the cross-product may be sufficient as a good image enhancement model as evidence delineated in Figs. 5, 6, 7. However, the cross-product model is definitely better than the linear model in its enhancement capability. In addition, the difference in computational time of obtaining the PL-equivalent and AL-equivalent images between the linear and the cross-product models is only (80 - 53) = 27 seconds. Therefore the cross-product model is recommended in this aspect. Of course, the quadratic model is still the best among the three, but the computational time required to perform is too long and the enhancement is not that much better than that from the cross-product model. Therefore the quadratic model is not recommended.

Also notice that, the dual energy technique has an advantage over the temporal subtraction technique for we always get the subtraction image using K*(High Energy Image - Low Energy Image), where K is a constant from the dual-energy technique. Besides, dual-energy provides more options, namely selective images.

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CT MAGNIFICATION TECHNIQUES

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Magnification techniques have long been used in radiography to provide greater detail in areas of special interest (1). Two general techniques can be employed for radiographs. Optical methods employ a lens to magnify images recorded on routine radiographs. Radiographic methods use an increased distance between the object and the film to produce an enlarged x-ray image. CT systems are also capable of producing magnified images in a variety of ways. Optical magnification of a filmed CT image is possible, but is of limited value because it tends to enhance the discreet picture elements (pixels) or the raster of the television screen from which the image was photographed. At least one CT system employs direct radiographic magnification by physically moving the x-ray source closer to the patient and the detector array further from the system's center of rotation where the patient is located. Many CT systems provide two other types of magnification techniques. One technique is to compute closely spaced values between the centers of pixels in an image from the CT values. This interpolation technique is somewhat analogous to optical magnification techniques because it requires only the digital CT values from the reconstructed image. The second technique is to compute more closely spaced CT values over some area of the object from the projection values sometimes referred to as "raw" data. Because this method cannot be carried out from a reconstructed image alone, it is somewhat analogous to radiographic magnification techniques.

Our department has acquired a Somatom 2 CT system which provides both interpolative and reconstructive magnifications. We have performed several experiments to learn in detail how these methods work and have compared

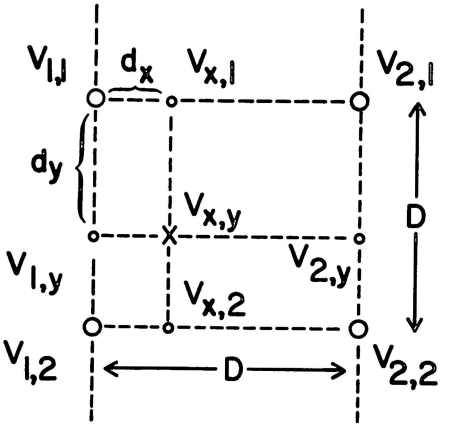


Figure 1. Bilinear interpolation (see text).

the results they produce by magnifying mathematical and physical phantoms as well as clinical scans. Our impression is that the reconstruction magnifications are better than the interpolated ones, although they are relatively cumbersome to perform.

CT MAGNIFICATION TECHNIQUES

The use of linear interpolation should be familiar to anyone who has taken high school triginometry and has used the technique to estimate values which lie in between the ones listed in tables of logarithms or the trigonometric functions. The basic assumption is that the value of a function at a point between two points at which the function is known is proportional to the distance of that point from the known points. For digital images this method is generalized to compute intermediate values of a discreet two-dimensional function. The method is illustrated in Figure 1 which represents a greatly enlarged area of a digital image in which four pixels separated by a distance, D, have values $V_{1,1}$, $V_{1,2}$, $V_{2,1}$, and $V_{2,2}$ as shown. We wish to compute an interpolated value, $V_{x,y}$, at

an intermediate point such as the one represented by the x in the figure. Linear interpolation between the values $V_{1,1}$ and $V_{2,1}$ can be used to compute the value $V_{x,1}$. We find that

1.
$$V_{x,1} = V_{1,1} + \frac{d_x}{D} \cdot (V_{2,1} - V_{1,1})$$
$$= \frac{(D-d_x) \cdot V_{1,1} + d_x \cdot V_{2,1}}{D}$$

Similarly, the linear interpolation between $V_{1,2}$ and $V_{2,2}$ yields

2.
$$V_{x,2} = \frac{(D-d_x) \cdot V_{1,2} + d_x \cdot V_{2,1}}{D}$$

The value at $V_{x,y}$ is then computed by linear interpolation between $V_{x,1}$, and $V_{x,2}$ giving

$$V_{x,y} = \frac{(D-d_y) \cdot V_{x,1} + d_y \cdot V_{x,2}}{D}$$

Substituting the values for $V_{x,1}$ and $V_{x,2}$ from equations 1 and 2, we find

3.
$$V_{x,y} = \frac{(D-d_y) \cdot (D-d_x) \cdot V_{1,1} + (D-d_y) \cdot d_x \cdot V_{2,1} + d_y \cdot (D-d_x) \cdot V_{1,2} + d_x \cdot d_y \cdot V_{2,1}}{D^2}$$

The algebraically inclined reader may wish to verify that the same result is obtained by interpolating between $V_{1,y}$ and $V_{2,y}$. The formula defines the value at any point in a digital image as a relatively simple, linear combination of the values of the four neighboring points.

Other schemes to accomplish the task of defining image values between known points are available. A very simple method is to assign any point the value of the closest known point. This is often referred to as the "nearest neighbor" method. A rather complicated method is to convolve the image with a two-dimensional sinc function as follows:

$$V_{x,y} = \sum_{i=1}^{N} \sum_{j=1}^{N} V_{i,j} \, \mathrm{sinc}\left(\frac{x}{D} - i\right) \cdot \mathrm{sinc}\left(\frac{y}{D} - j\right)$$

where N is the number of pixels along the side of the digital image, and

$$\mathrm{sinc}(u) = \frac{\sin(\pi u)}{(\pi u)}$$

Although these techniques all give (slightly) different results for the value assigned to an intermediate point, they all compute these values from only the values in the digital image.

Reconstructve magnification techniques are fundamentally different because they require projection data for the calculations. A mathematical discussion of reconstruction techniques is far beyond the scope of this paper, but some rudamentary understanding of the methods employed is required to appreciate how they can be used to produce magnified images. We may devide the production of a CT scan by filtered backprojection into three steps:

1) Acquiring several views of the patient.

2) Filtering the projection values for each view.

3) Back projecting these filtered projection values.

A CT "view" is defined as a set of non-intersecting projections which taken together "cover" the patient. In first generation scanners a view is obtained by translating the X-ray tube and the detector across the gantry so that the attenuation values along many narrow bands through the patient are measured. The measurements may be performed so that the bands do not overlap, and so that there are no gaps between them. The bands can be numbered by integers between one and N. Each of these attenuation

values is converted into a projection value so that N projection values are obtained for the view. The gantry is then rotated a slight amount and another view is taken by measuring the attenuation at N points as the tube-detector pair is again moved or "translated" across the patient. In third generation scanners a view is obtained by simultaneously exposing an array of detectors to a fan-beam of radiation which covers the patient. The detectors may again be numbered one through N yielding a collection of N projection values associated with the view. The tube-detector array system is rotated slightly, and the detectors are again exposed to radiation resulting in another view of N projection values. For either scanning geometry several views, say M views, each of which comprises N projections will be obtained.

The next step in making the CT scan is to filter the projection values in each view. If this operation were not carried out, the backprojection operation described below would result in a very fuzzy CT image. Furthermore, different kinds of filter functions or "kernals" can be applied, and these will produce different reconstructions. In part, the choice of the filter is governed by the geometry of the scanner. That is, a parallel beam scanner will need a different kind of filter than a fan beam scanner. However, the filter can also be chosen to provide more or less fuzziness or sharpness in the reconstructed image. Although more sharpness might seem to be desirable in selecting a filter, for a finite number of views each having a finite number of projections, kernals which increase the sharpness also enhance sampling artifacts so that some compromise must be made.

The backprojection operation is simply the reverse of the first operation in which the N projection values for each view were defined - except that the values which are backprojected have been filtered in step two. Mathematically the backprojection at any point is calculated by adding up the appropriate (filtered) projection values for each of the M views obtained in step one. The determination of which projection value for any view should be added into the sum for a particular point in the image is quite simple. It is that projection for which the point casts a shadow. For fan-beam scanners, backprojection also requires a geometrical weighing factor to correct for beam divergence.

Note that the back projection operation can be carried out for any point in the reconstruction field. This implies that reconstructed values can be computed at as many points which are as closely spaced as we wish. In practice the number of points is restricted by the amount of computation time and by the amount of computer memory available to store or display the results. Thus CT systems generally produce an n x n image in a fixed amount of reconstruction time. However, the n x n image can be used to represent relatively widely-spaced values across the entire reconstruction field or to represent relatively closely-spaced values across a smaller portion of the field.

IMPLEMENTATION OF MAGNIFICATION ON THE SOMATOM 2

The specifications of the Somatom 2/Evaluskop system in use at the University of Chicago have been described in detail elsewhere (2). The system provides both interpolative and reconstructive magnification techniques. The operation of these functions is described in some detail below.

The interpolative magnification technique provided is activated by entering the "EX" (expand) function. Two methods of utilizing the function are provided. The first requires that the operator type a magnification factor which must lie between 1.01 and 5.12. The operator must then specify a row and column number which will determine the center of the magnified view. The second method allows the operator to specify the magnification factor and area of interest interactively. The system superimposes a bright square on the CT image in the display CRT. The operator may vary the size of this square by manipulating a potentiometer knob, and the size of the square, in turn, determines the magnification factor. The operator may also move the square to any desired location within the image by manipulating the interactive bit pad, and this determines the center of the enlarged image. The second method is used much more frequently than the first, perhaps in part because it requires no keyboard entry. More importantly, the second method allows the operator to see precisely what portion of the image is to be magnified. The expand function may be applied to any image in the display memory including one which has been previously expanded. As a result, an image may be magnified infinitely by this technique, although the value of such a procedure is highly questionable.

The system produces reconstructive magnified images directly from raw data using the "RC" (reconstruct) function. The program begins by asking the operator to specify an "enlargement factor" or magnification in the range of 1.0 to 9.9 for body-mode scans, or 2.0 to 9.9 for head-mode scans. The program will accept any value in this range with one significant figure to the right of the decimal point (i.e., 7.5 is

legal, but 7.55 is not). This magnification factor governs the spacing between points for which values will be computed in the enlarged reconstruction. If D is the pixel spacing then for a magnification, M,

$$D = \frac{2.08}{M} \text{ mm}$$

Thus, at a magnification of 2 (standard for a head-mode scan) the pixel spacing is 1.04 mm., and at the maximum magnification of 9.9, the pixel size is 0.21mm.

The program next asks the operator to specify coordinates for the center of the magnified image. In this process it displays a diagram of the following general form:

-N,N N,N

0,0

-N,-N N,-N

where N is an integer between 1 and 5, and is computed from the "enlargement factor" according to the first two columns of Table 1. The operator

TABLE 1

M	N	L (cm)	L^2/Gantry Area %
1.0 - 1.4	0	53.3 - 38.1	126.8 - 64.8
1.5 - 1.9	1	53.3 - 42.1	126.8 - 79.1
2.0 - 4.9	2	53.3 - 21.7	126.8 - 21.0
5.0 - 5.9	3	26.7 - 22.6	31.8 - 22.8
6.0 - 6.9	4	26.7 - 23.2	31.8 - 24.0
7.0 - 9.9	5	26.7 - 18.9	31.8 - 15.9

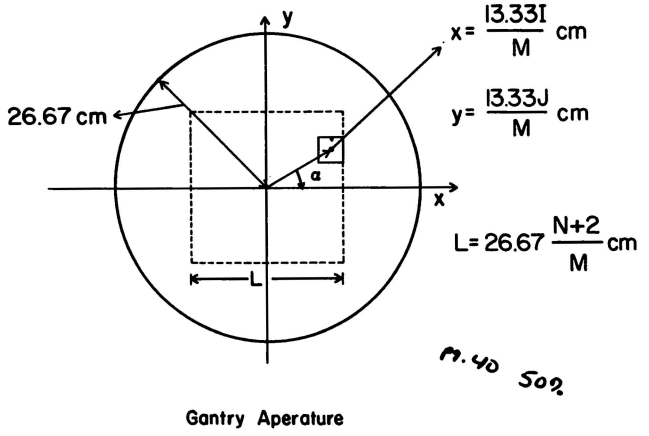


Figure 2. Diagram of Gantry aperture. The small square centered at (x,y) represents an area to be magnified by factor M. The large square represents the union of all possible magnification areas at the factor M.

specifies the center by typing coordinates of the form I,J where I and J are either positive or negative integers whose absolute values are less than or equal to N. If M is 1.4 or less, the operator has no choice and the program automatically selects the center at 0,0 which corresponds to the center of the gantry aperature. The location of the center of the magnified picture may may be computed from M, and I and J. We have found that

$$x = 13.33 \cdot \frac{I}{M} \text{ cm},$$

and

$$y = 13.33 \cdot \frac{J}{M} \text{ cm},$$

where x and y measure respectively the distances above and to the right of the center of the gantry aperature (see Fig. 2). The length of the side of the reconstructed view can be computed from the pixel spacing and the fact that the image is always 256 x 256 pixels. The corners of the reconstruction will lie half this distance in the x and y directions from the center of the magnified image so that the location of the corners can also be computed. It is interesting to note that the center of a

reconstruction which lies contiguously above the one obtained by specifying (I,J) is always obtained by specifying (I,J+4) at the same magnification, etc.

A consequence of the fact that the absolute values of I and J cannot exceed N is that not all areas in the gantry can be reconstructed at the higher magnification factors. The union of all possible zoom reconstructions at a given magnification factor forms a square (dashed line in Fig. 2) with a side of length L. L can be computed by noting that the upper left coordinate of a magnified view at (-N,N) will be (-(N+2), N+2) and the upper right corner of the magnified view at (N,N) will be (N+2, N+2). Thus, in the I,J coordinate system,

$$L = (N + 2) - [-(N + 2)] = 2N + 4$$

To convert to centimeters in the gantry coordinates requires only multiplication by the factor (13.33/M) as in equation 4. Thus,

$$L = 26.67 \cdot \frac{N + 2}{M} \text{ cm},$$

where N is determined from M, as shown in column 2 of Table 1. The range of L corresponding to different values of N is shown in column 3 of Table 1. The total area of the region within which a given magnification can be achieved is simply L^2. The ranges of these areas for different values of N are expressed as percentages of the area of the gantry aperture $(26.7)^2$ cm^2 in Table 1. Obviously, the size of the magnifiable region is not a smoothly decreasing function of the magnification factor. For example, a much larger portion of the gantry aperture can be viewed at a magnification of 2 than can be viewed at a magnification of 1.9.

It is interesting to examine the maximum magnification which can be

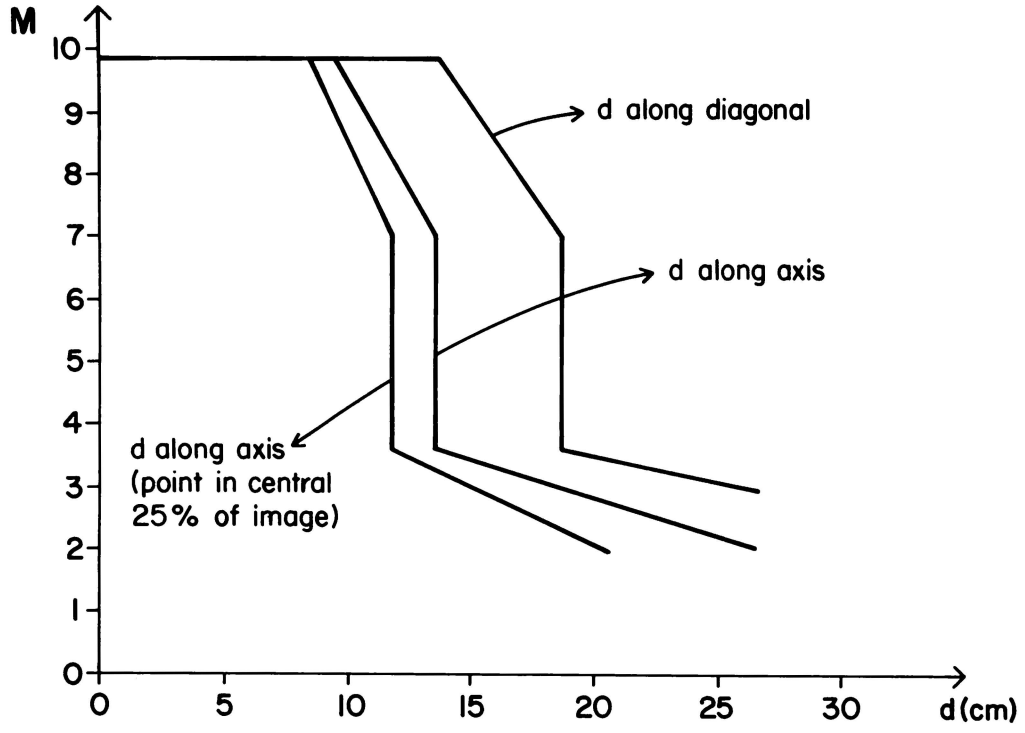


Figure 3. Graph of the maximum magnification which can be applied to a pixel as a function of the pixel's distance from the center of the Gantry aperture.

applied at a point in the gantry aperture as a function of its distance from the center of rotation. Unfortunately, the maximum obtainable magnification depends not only upon this distance but also upon the angle formed by a line connecting the area to the center of rotation and the nearest axis (angle in Fig. 2). The maximum obtainable magnification, $M_{max}(d,\underline{\alpha})$ for a point on one of the axes (x = 0) is given in Fig. 3. For a point at distance d, which is off-axis by an angle , the maximum factor may be computed by

$$M_{max}(d,\alpha) = M_{max}\left(\frac{d}{\cos\alpha}, 0\right)$$

where $0 < \alpha < 45^{o}$. Values of M_{max} along the diagonal are shown in Fig. 3. It should be noted that frequently the maximum magnification for any point which lies more than about 13 cm. from the center can be achieved only by forming a magnified view which has the point very near the edge of the view. Under these circumstances, the point may lack some degree of image "context" so that clinical interpretation may become more difficult. A reasonable requirement might be to insist that the point be located within the central 25% of the magnified view. The maximum achievable magnification fulfilling this criterion for a point along an axis is also given in Fig. 3. It may be sensible to permit higher magnification near the center of the gantry than near the periphery because the sampling in the latter region may, in some sense, be less than that near the edge. However, the abrupt changes in M_{max} and its angular dependence are more difficult to rationalize.

The system next asks the user to select a convolution kernal by typing an integer between one and four. Kernals 1 and 2 are used for body mode, while kernals 3 and 4 are employed for head scans (presumably because they attempt to compensate for the low density artifact sometimes seen just inside the calvarium). Kernals 2 and 4 are described as producing smoother images than 1 and 3 respectively. The system also offers the operator a choice of whether or not to perform a "balancing" operation. The nature of this operation is not known to us.

Another reconstructive magnification technique is available on the Somatom 2 via the "HR" (high resolution) function. This is quite similar to the "RC" function except that the minimum magnification factor allowed

is 4.0 and the operator is not provided with a choice of kernals or an option regarding "balancing." Furthermore, the high resolution reconstruction requires raw data from a 720-view scan. We presume that the method utilizes a kernal which provides a sharper image, but have no information regarding the details of the techniques employed.

Once the parameters are specified, computing the values for a reconstructive magnification requires approximately six seconds (slightly more for the high resolution technique). The methods suffer from the same deficiencies in human engineering as the first method of utilizing the expand function described above. Even an experienced operator sometimes has to specify the center coordinate two or three times before producing an appropriately centered image at the higher magnification factors. The vendor seems to recognize this deficiency and has indicated informally to us that some improvement may be expected.

METHODS AND MATERIALS

We have compared the various magnification techniques available on the Somatom 2 by applying each of them to several objects and comparing the results obtained. That is, we have applied the same magnification techniques to the same areas of several images and examined the differences in the enlargements obtained. We soon discovered a small problem. The reconstructive and interpolative magnifications were mis-registered by a fraction of a pixel space. This discrepancy is certainly of no clinical importance, but made comparison of the methods difficult. To circumvent this problem we first verified our suspicion that the interpolative technique employed by the system was in fact the bilinear

interpolation method described above. This was easily accomplished by printing out the numbers obtained from expanding a simple image which contained a known value at a single pixel and zeros elsewhere. We then wrote our own bilinear interpolation program which employed the same methods for specifying the location of the area to be magnified and computed values at the same points as those used for the reconstructive magnifications. In writing this program as well as the others described in this paper we have employed a "user" library of programs kindly supplied by Siemens which provides access to many of the special hardware and software features of the Somatom 2 system.

The objects which were enlarged included the following (Fig. 4): A mathematical phantom composed of a cylinder of radius 1.04 mm. placed at the center of rotation; a real phantom containing a variety of objects with enlargements made in the area of a plastic block containing multiple small holes; a normal head scan near the base of the skull with enlargements in the region of the sella turcica; a body scan of a normal upper chest with enlargements in the region of the apex of the left lung. All scans were done in high resolution mode with 720 views taken at one-half degree increments. The raw data were stored on magnetic disk. The projection values for the mathematical cylinder were computed by a program we have written which allows the operator to "place" a small cylinder at any location in the reconstruction field and to specify both the radius and the density of the cylinder.

Each object was reconstructed at the lowest possible magnification factor - one for body mode scans, and two for the head mode scans. The

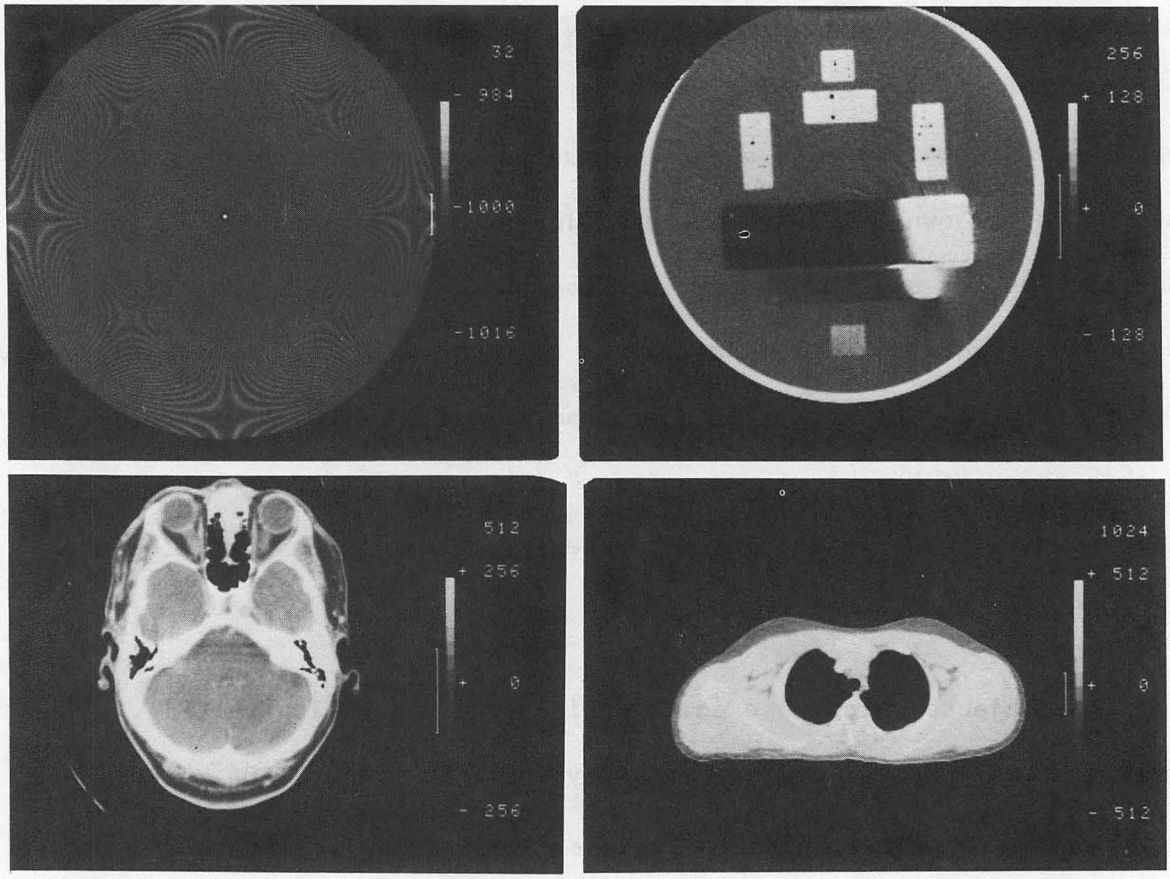


Figure 4. Objects used to evaluate magnification techniques.

4-a Mathematical point (1X) at the center of rotation. Note that the visibility of the sampling artifacts around the central point is due to the low threshold and narrow window settings shown.

4-b The "junk" phantom scanned in "head" mode at 2X magnification.

4-c Head scan near the base of the skull (also at 2X).

4-d Scan through the upper thorax of a pediatric patient (body mode at 1X).

selected region of interest for each scan was then enlarged to a magnification factor of eight using four different techniques: 1) Our version of the "expansion" or bilinear interpolation technique (EX); 2) The reconstruction method with kernal number 1 (K1); 3) The reconstruction method with kernal number 2 (K2); 4) The "high resolution" reconstruction technique (HR). The resulting images were inspected, and difference images representing

the K1 image subtracted from the other three magnification images of each area were formed and inspected. Finally, we computed the change in the relative information content of the images which resulted from magnification, and we computed a variety of "distance" measures in an attempt to see which magnification techniques gave the most similar results.

The information content, I, of an n x n pixel digital image m bits "deep" is defined by the equation,

$$I = -n^2 \sum_{i=1}^{2^m} p_i \log_2 p_i$$

where $p_i = \frac{h(i)}{n^2}$

and h(i) is the number of pixels which have a value i

It can be shown that this quantity reaches a maximum value when an equal number of pixels has each possible value, i.e., when $h(i) = \frac{n^2}{2^m}$. The maximum value of the information content is then $I_{max} = n^2 m$.

We define the relative information content, I_r, of an image to be its information content divided by I_{max}. Thus, $I_R = \frac{I}{I_{max}}$.

It should be emphasized that the information content of an image as defined above does not correspond very well to our intuitive concepts of diagnostic information or resolution. Nevertheless, information theory provides the basis for some techniques such as histogram equalization which offer the potential ability to improve display techniques for digital diagnostic images. Therefore, it is at least interesting to explore the use of such concepts in dealing with medical images.

Measuring the similarity between two images is a difficult problem because there is no single number which can quantify the different kinds of discrepancies between similar pictures. The usual approach is to calculate several measures of the difference or "distance" between pictures and to interpret these data judiciously. We have used two distance measures from the literature (3) which are defined by the following equations:

$$d_1 = \left(\sum_{i=1}^{n} \sum_{j=1}^{n} (t_{i,j} - r_{i,j})^2 \Big/ \sum_{i=1}^{n} \sum_{j=1}^{n} (t_{i,j} - \bar{t})^2 \right)^{\frac{1}{2}}$$

$$d_2 = \sum_{i=1}^{n} \sum_{j=1}^{n} |t_{i,j} - r_{i,j}| \Big/ \sum_{i=1}^{n} \sum_{j=1}^{n} |t_{i,j}|$$

where $t_{i,j}$ and $r_{i,j}$ are the values of the "true" and "reconstructed" images at the point (i,j), and $\bar{t}$ is the average value of all pixels in the true image.

The quantity d_1, called a "normalized root mean squared distance measure," is sensitive to large differences between the images in a few places. The quantity d_2, or "normalized mean absolute distance measure," emphasizes the importance of small differences at many places in the image. For a third measure we have employed the relative information content, I_r, of the image formed by subtracting the two magnified images. In this regard, it is important to note that the "depth" of an image formed by adding two images each of which is m-bits deep is 2^{m+1}.

RESULTS AND CONCLUSIONS

The relative information content of the subset of each image which was enlarged has been computed. The values are shown in Table 2 and compared to the relative information content of the four types of enlargements for each object. The change in relative information content was computed

Table II: Relative Information Content for Magnified Images

	Point	Phantom	Sella	Lung
K1 (Subset)	.17651	.52443	.76551	.69604
K1 at 8X	.13307	.51340	.79283	.74714
K2 at 8X	.09157	.47289	.79273	.72888
HR at 8X	.35073	.62178	.80767	.80550
EX at 8X	.15410	.49076	.79624	.72954

Table III: Change in Relative Information Content with Magnification

	Point	Phantom	Sella	Lung
K1	-.04344	-.01103	.02732	.05110
K2	-.08494	-.05154	.02722	.03284
HR	.17422	.09735	.04216	.10946
EX	-.02241	-.03367	.03073	.03350

by subtracting the value for the subset from the value for each type of enlargement, and these values are shown in Table 3. We were somewhat surprised to find that for all but the high resolution (HR) enlargements of the point and the phantom there was a decrease in relative information content. The enlargements made from clinical images always showed an increase in information content. For all objects the greatest increase in relative information content was achieved using the high resolution reconstructive magnification technique.

The similarity of unmagnified images done using kernals one and two, and the similarity of the K1 magnified images to the magnified images

Table IV: Similarity Between Images Reconstructed or Magnified by Different Techniques

		D_1	D_2	I_r
Original, K1 vs K2	Point	.02384	.09003	.07120
	Phantom	.00615	.02650	.18019
	Sella	.02486	.04479	.23206
	Lung	.02792	.03129	.21736
8X mag. K1 vs. K2	Point	.02712	.39858	.05109
	Phantom	.00346	.16735	.19253
	Sella	.00963	.05799	.28605
	Lung	.03812	.06064	.26935
8X mag. K1 vs. HR	Point	.31990	.75956	.17975
	Phantom	.01898	.65205	.26850
	Sella	.04405	.24321	.35226
	Lung	.10586	.17393	.33551
8X mag. K1 vs EX	Point	.04823	.82956	.07609
	Phantom	.00232	.11184	.16732
	Sella	.00931	.05799	.25678
	Lung	.05836	.10312	.36477

obtained by the other three techniques were evaluated using the two distance measures and the relative information content of the difference image as defined above. For the distance measures the "true" image was taken to be the K1 reconstruction because it presumably represents the best compromise between sharpness and sampling noise. The results of these computations are presented in Table 4. A careful study of these data will show that if the similarity of the magnified images to the K1 magnification for any object are simply ranked, the order will be the same no matter

which distance measure is used. There is one exception to this rule. The ranking from most to least similar for the point is (K2,EX,HR) if d_1 or I_r is employed, but it is (K2,HR,EX) if d_2 is used. This implies that the various distance measures are fairly consistent with one another. For all the magnified objects the HR reconstructive technique produces an image which is least similar to the K1 image. For the mathematical point and the lung images the K2 magnifications are most similar to the K1 enlargements, but for the phantom and the sella the EX images are closest to the K1 magnifications. Although this result might imply that the EX and K2 magnifications are at least roughly equivalent, this hypothesis is not supported by our subjective evaluation of the images.

The various images for which quantitative results and comparisons are presented above have also been reviewed by ourselves and our colleagues. It requires very little experience to learn how to predict accurately from viewing an 8x enlargement which technique has been used. The EX interpolative magnifications are easily identified because they tend to magnify points into squares (Figure 5) and this produces a "sawtooth" pattern along diagonal lines (Figure 6). The HR reconstructive technique tends to create a "honeycomb" noise artifact (Figure 7) in the magnified images. A K2 enlargement is distinguished from the EX and HR enlargements by its lack of artifact, but if it is compared side-by-side with a K1 magnification the greater "fuzziness" of the K2 image is apparent in clinical scans (Figure 8). In examining the difference images, we have "re-discovered" an observation originally made by Winter et. al. (4) that subtracting a fuzzier image from a sharper one enhances edges by a method known as

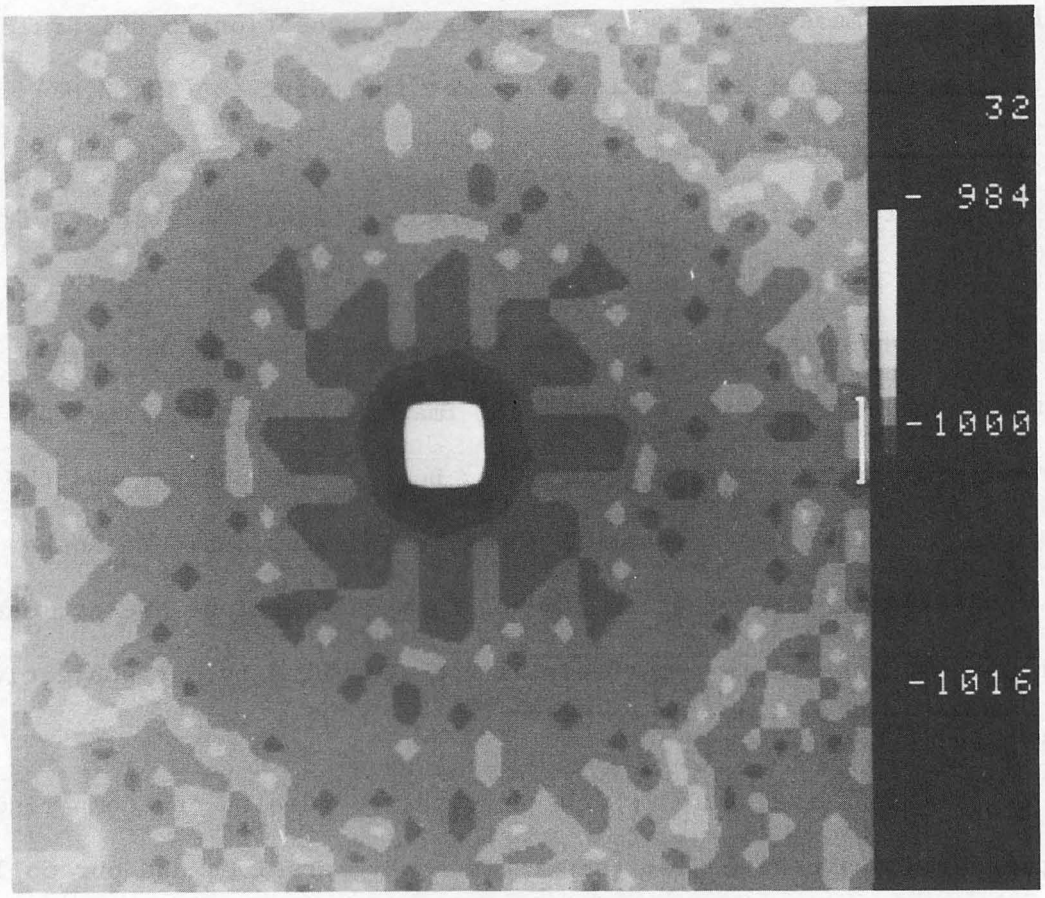


Figure 5. "Expand" (EX) magnification (8X) of the point (4-a). Note that the round point has taken a square shape from the bilinear interpolation technique.

unsharp masking (5). This technique (Fig. 9) can provide an increase in certain types of detail without producing the artifacts seen in HR magnifications.

SUMMARY AND CONCLUSIONS

Our overall impression is that reconstructive magnifications are superior to interpolative enlargements. In addition to the human engineering problem described above which makes the reconstructive enlargements difficult to perform, there is another serious drawback to their routine use in practice. They require the availability of raw data. For the

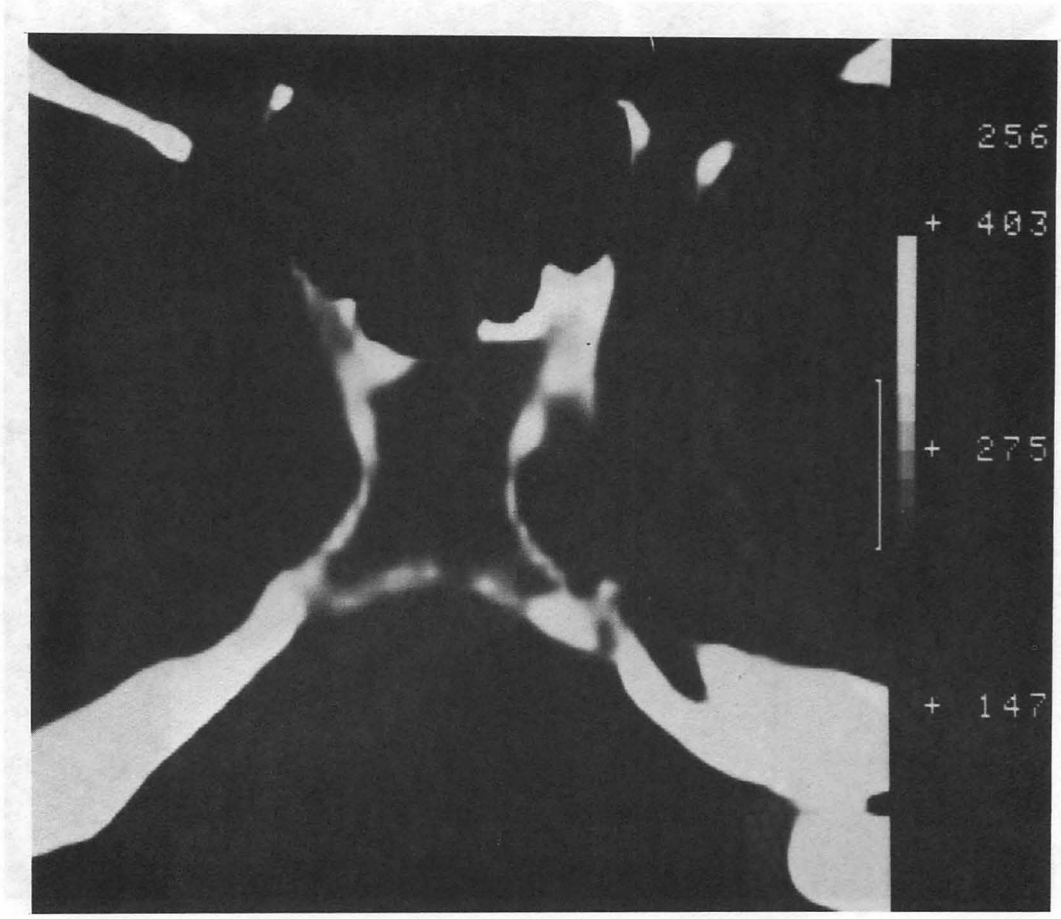


Figure 6. "Expand" (EX) magnification (8X) in the region of the sella of the head shown in 4-b. The window settings have been chosen to bring out the "sawtooth" pattern along diagonal boney ridges.

Somatom 2 the raw data is roughly six times as voluminous as the data in a reconstructed image, so that storage of the raw data is relatively problematic. Even if one is willing to acquire ample storage for the raw data by purchasing additional disk drives and disk packs, the system is not well adapted for storing the data as scans are done. In order to store the raw data for a single slice, the technologist must type in a special command and then wait for a period of approximately 7 seconds while the computer transfers the raw data from one disk to another. The system does allow magnified reconstructions to be done conveniently as

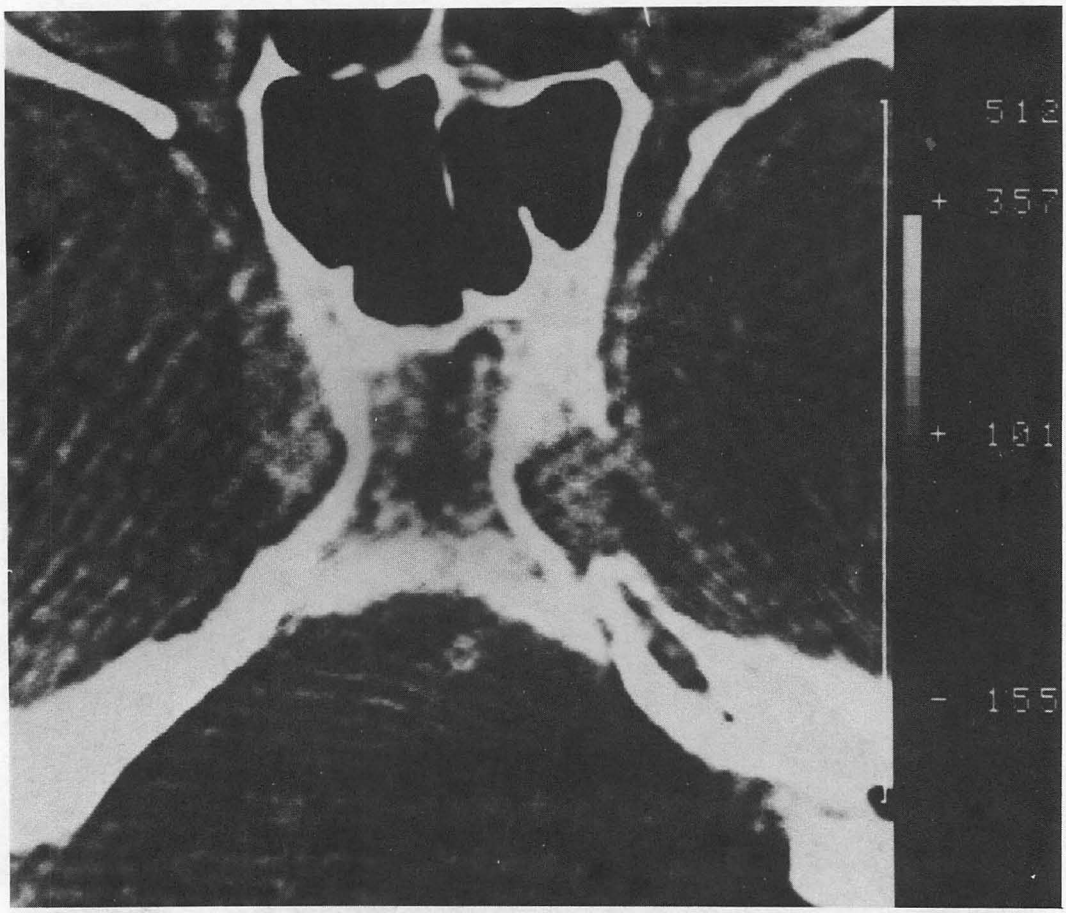


Figure 7. Sella magnified to 8X by the high resolution (HR) reconstruction technique. Note the enhancement of the sampling "noise" in soft tissue regions.

the patient is scanned, but only the magnified images are stored--the raw data being discarded unless the technologist intervenes. Under this circumstance not only is it impossible to perform different types of magnification in retrospect, it is also impossible to view any structures within the patient which lie outside the original magnified area. We believe that the ability to store raw data for a series of scans without increasing the time per scan is quite feasible, and that it might well prove clinically useful in selected cases.

In summary, we have evaluated an interpolative method and several

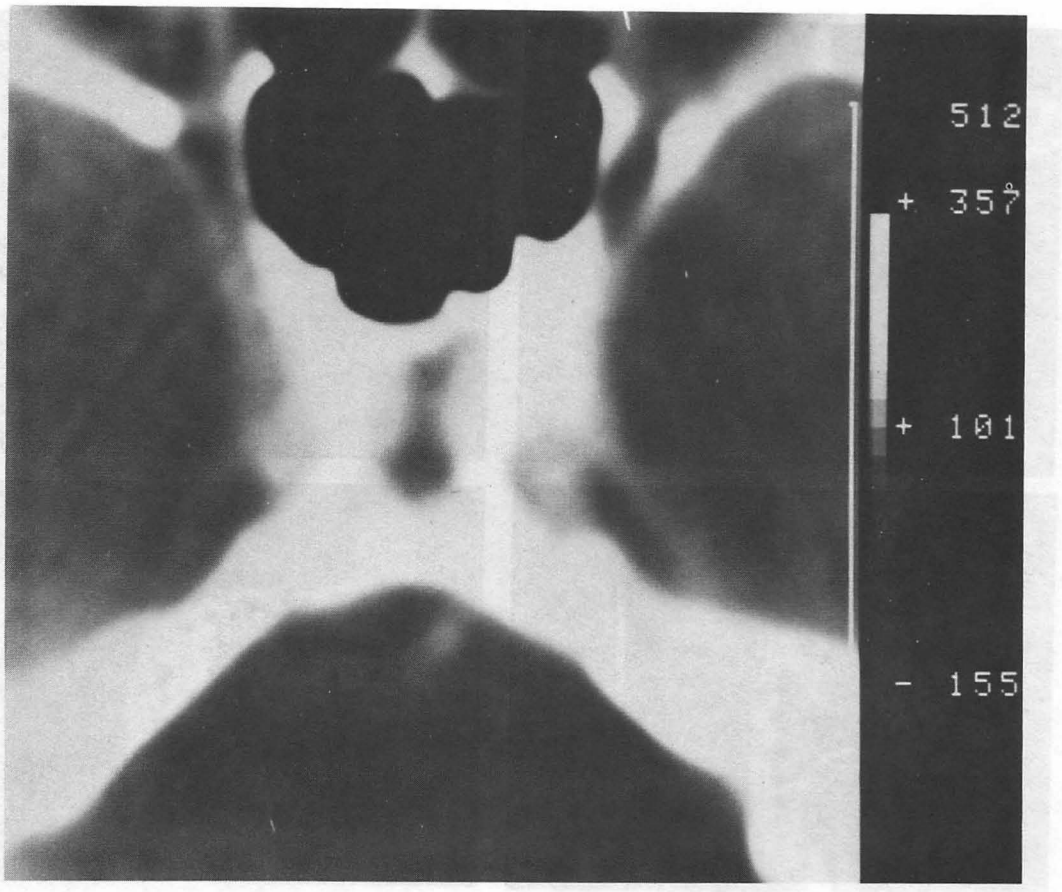


Figure 8. Sella magnified to 8X with the "smoothing" kernel (K2).

reconstructive techniques which produce magnified CT images. We have applied these methods to both phantoms and clinical scans and have examined the enlarged images both quantitatively and subjectively. We conclude that the reconstructive techniques provide better images, but we note that they are inconvenient to use in routine clinical situations with our current CT system. We are especially impressed with the anatomic detail provided by unsharp masking techniques previously described.

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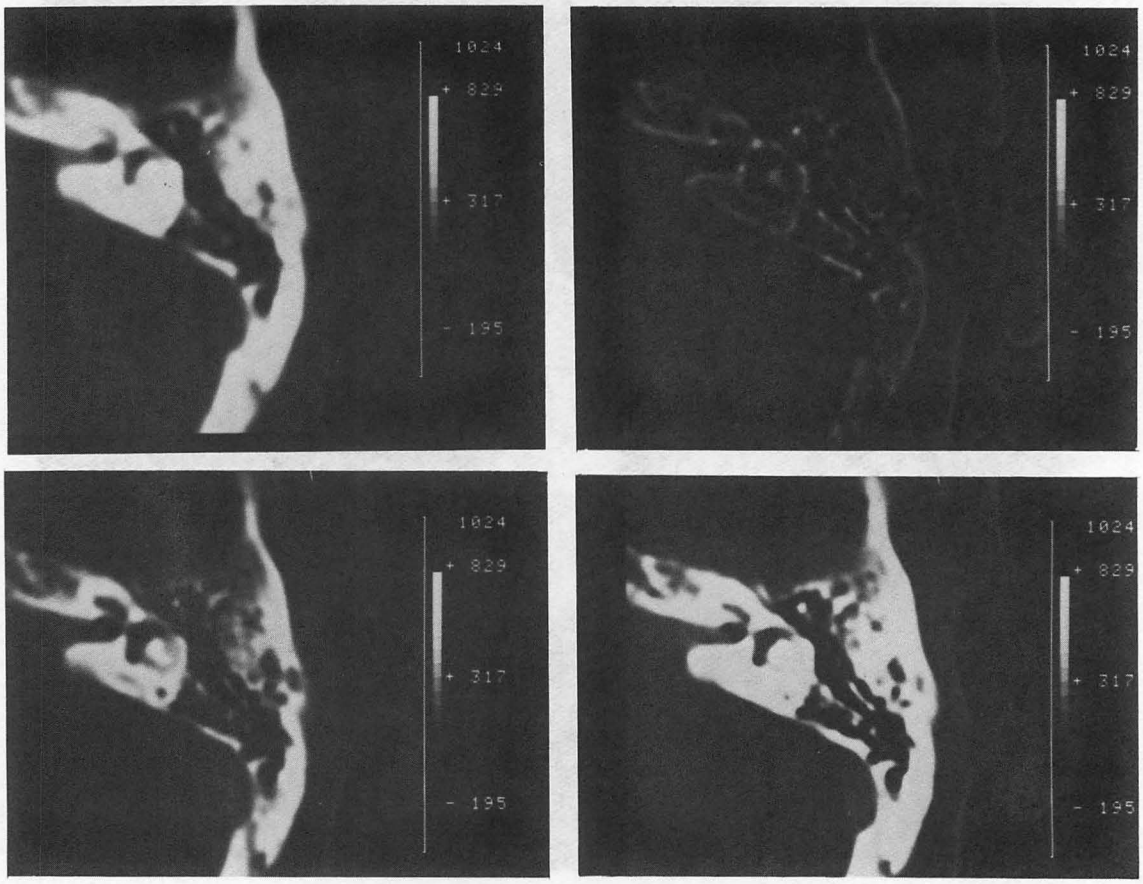


Figure 9. Unsharp masking applied to magnifications of the middle ear for the head scan (4-c).

9-a 8X magnification using the "normal" kernel, K1.
9-b Edge-enhanced "mask" obtained by subtracting the k1 image (9-a) from the HR image (9-d).
9-c Edge-enhanced image obtained by adding the mask (9-b) to the original image (9-c).
9-d High resolution (HR) reconstruction of the middle ear.

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CLINICAL EVALUATION OF A HIGH-QUALITY DIGITAL IMAGE PROCESSING SYSTEM

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From its inception, radiology has thrived on developments in basic technology. We are now witnessing a revolution in radiology which is a consequence of rapid advances in computer technolgy. Many of the diagnostic images which radiologists currently use are digital. These include many ultrasound and nuclear medicine images, all CT images, some fluoroscophic and a few radiographic images, and finally nuclear magnetic resonance images. It is likely that we are seeing only the tip of the iceberg, and that radiologists of the future will deal only with digital data - a film being regarded with the same curiosity that we now reserve for the x-ray plates of earlier years.

This digital revolution provides the radiologist with a vast array of new challenges and opportunities. Many of these involve novel ways of collecting data either by using different energy modalities such as sound or radio frequency electromagnetic radiation or by using more sensitive x-ray detectors as is done in CT scanning. Another set of opportunities is provided by the limitless ways a computer can manipulate the data collected. These range from complex reconstruction techniques to relatively simple data correction schemes which can compensate for systematic errors in imaging devices. Often a digital technique developed for one type of image or device can be used profitably with another.

This paper describes our experience with a high-quality image processing system (1) which uses conventional radiographs for input and also produces films as output. Although this may seem somewhat anachron-

istic in light of the "filmless" radiology promised in the discussion above, many types of important images are now available only on film, and radiologists have considerably more experience judging the diagnostic quality of images recorded on film than those recorded in digital form and displayed on television screens. Furthermore, the processing techniques we describe should be applicable to the high resolution images we hope to obtain directly from digital fluoroscopy and radiography in the future. The experience gained with this system should help bridge the gap between the "analogue" radiology of the present and the digital radiography of the future.

SYSTEM DESCRIPTION

A schematic diagram of the system is shown in Figure 1. Basically, the system has three major parts: a reading device which produces a digitized version of the original radiograph; a computer system which can process the digital image; and a writing device which provides film output of a processed image. A radiograph is mounted on the transparent cylindrical read drum and illuminated by a halogen tungsten lamp. The light transmitted through the film passes through a condenser lens and an aperture and is detected by a photomultiplier tube. The electrical output of the photomultiplier is converted by a logarithmic amplifier into a signal corresponding to the optical density of a small area on the film. This density signal is digitized and the digital value is then available for processing or storing by the computer. By rotating the drum, the computer records density values along a narrow line across the radiograph, and, by slowly moving the light source and detector

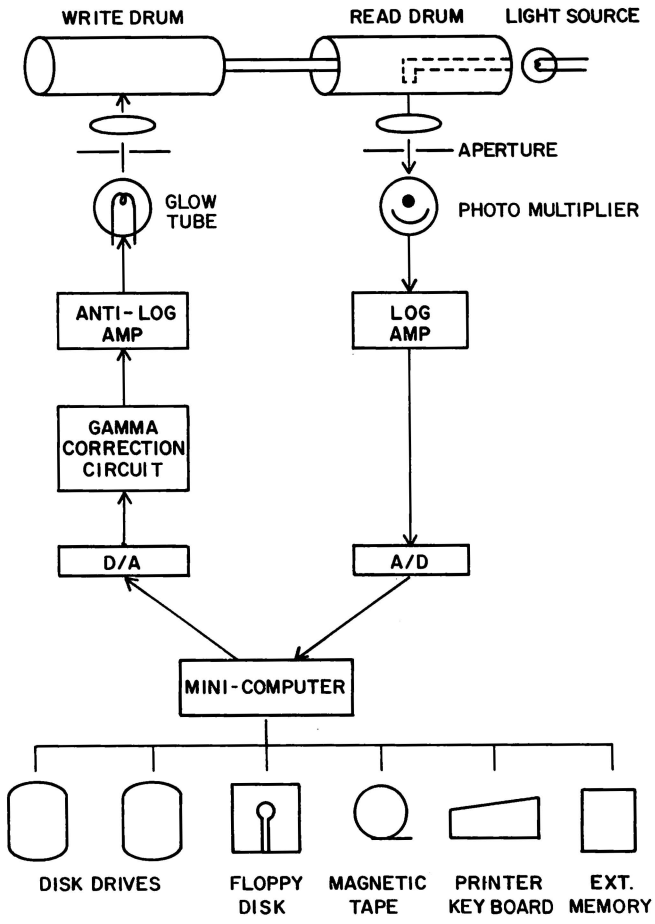


Figure 1. Schematic for the digital processing system

along the axis of the drum, density values over the entire radiograph are obtained.

The computer system may simply store the digital data produced by the reading system on magnetic tape, or it may process the digital image as the values are read and immediately output the processed image on the write drum. The digital values are converted to an analogue signal which is corrected to compensate for the non-linear response of the output film used. After processing by an anti-log amplifier, the output signal is used to modulate the light intensity of a glow tube which exposes a photographic film mounted on the write drum. The processed

Table I: System Specifications

SCANNER SYSTEM		COMPUTER SYSTEM	
MAXIMUM SIZE	35.6 CM X 35.6 CM	C.P.U.	NOVA 4X
DRUM SPEED	3.0 R.P.S.	MAIN MEMORY	128 KB
DENSITY RANGE	0.0 ~ 3.2 O.D.	MAGNETIC TAPE	1600/800 BPI
GRAY LEVELS	1024, 256	DISK DRIVE	2 X 25 MB
SIGNAL / NOISE	10^3 at D ≈ 0.0	FLOPPY DISK	1.26 MB
SAMPLING RASTER	20, 10, 5 PIX./MM	PRINTER	60 Char./sec
APERTURES	50, 100, 200 μM	EXTERNAL MEMORY	384 KB

image is obtained when the film is developed by conventional methods.

The system specifications are summarized in Table 1. The maximum size of radiographs that can be read is 35.6 cm x 35.6 cm (14" x 14"), which is large enough to accomodate most clinical radiographs. The optical density is controllable from 0 to 3.2, and 1024 gray levels (10 bits) are available. Since the electronic components of the system, including the light source, have a large signal-to-noise ratio (about 10^3) in the low-density region, it is possible to reproduce the wide density range of radiographic images accurately. Sampling rasters of 20, 10, and 5 pixels/mm are available, and an aperture size of 50, 100, or 200 microns may be selected.

The minicomputer is a NOVA 4X with 128 KB memory, 384 KB external memory for on-line processing, two 25 MB disk drives, one 1.26 MB floppy disk drive, one dual-density 800/1600 bpi 9-track magnetic tape drive, and one printer with keyboard. The two disk drives are used as work areas for certain types of image processing such as two-dimensional Fourier tansformations of the image. The floppy disk is used for program

storage. The magnetic tape can store original or processed radiographic image data. Digitized images stored on magnetic tape can be transferred to larger computer systems for more elaborate types of processing, and digital data produced by other imaging systems can be transferred back to the system for output onto film. To demonstrate this capability we performed high resolution CT reconstructions in 16 contiguous regions using projection data from the scan of a test phantom. The individual magnified images were stored on disc, and then the data were re-sorted to form a single CT image of the phantom containing 1024 x 1024 pixels. This image was output to film using the system described above.

PROCESSING TECHNIQUES

To date we have focused on informal evaluations of the on-line processing techniques which have been implemented on the mini-computer. These include linear and non-linear grey-scale manipulation as well as linear and non-linear unsharp masking. Linear grey scale manipulation is illustrated in Figure 2. The technique is quite simple. The processed grey level, G_p, at any point (x,y) in the image, is a linear function of the original grey level G_o at that point. That is,

$$1. \qquad G_p(x,y) = A \cdot G_o(x,y) + B$$

If the value of the constant B is zero and the value of the slope, A, is unity, no processing occurs. If the slope is greater than zero and less than unity and if the constant B is negative, the image will be "lighter" than the original. This technique can be used to recover information from overexposed films (Figure 3). If the slope is greater than unity, the pro-

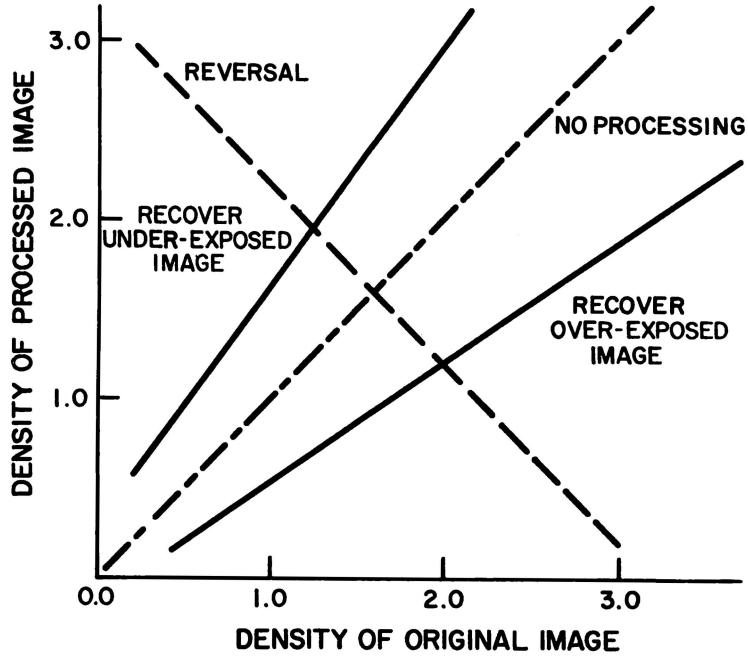


Figure 2. Graph illustrating linear grey-scale manipulation techniques

cessed image will be "darker" and higher in contrast than the original, and information from an underexposed film can be recovered (Figure 4). If the slope has a value of negative one, the grey scale will be reversed producing a "black bone" image. For angiograms, this can produce an image very similar to that obtained by photographic subtraction (Figure 5).

Unsharp masking is a technique (2-4) which enhances the edge content of images. The principle behind this method is illustrated in figure 6 and described mathematically by the folowing equation:

2. $$D_p(x,y) = D_o(x,y) + K \cdot [D_o(x,y) - D_{us}(x,y)].$$

The grey level or density of the original image at a point (x,y) is represented by $D_o(x,y)$. The orignal image will have a frequency content similar to that shown in the figure. The density at the same point in the unsharp image, $D_{us}(x,y)$, is computed as a weighted average of the original

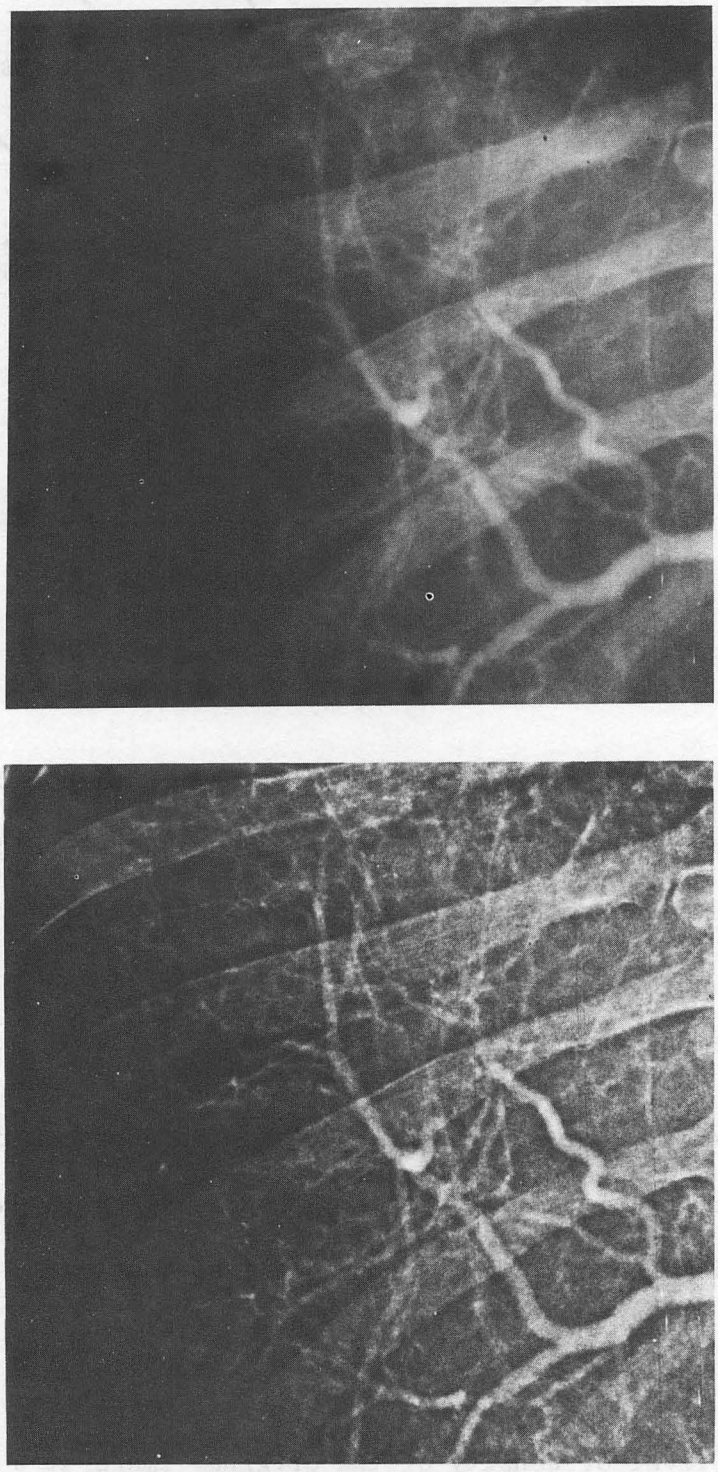


Figure 3. Hepatic angiogram -
3a. the original film is badly overexposed obscuring the smaller arteries
3b. the processed film compensates for the overexposure in the original improving the visability of smaller vessels

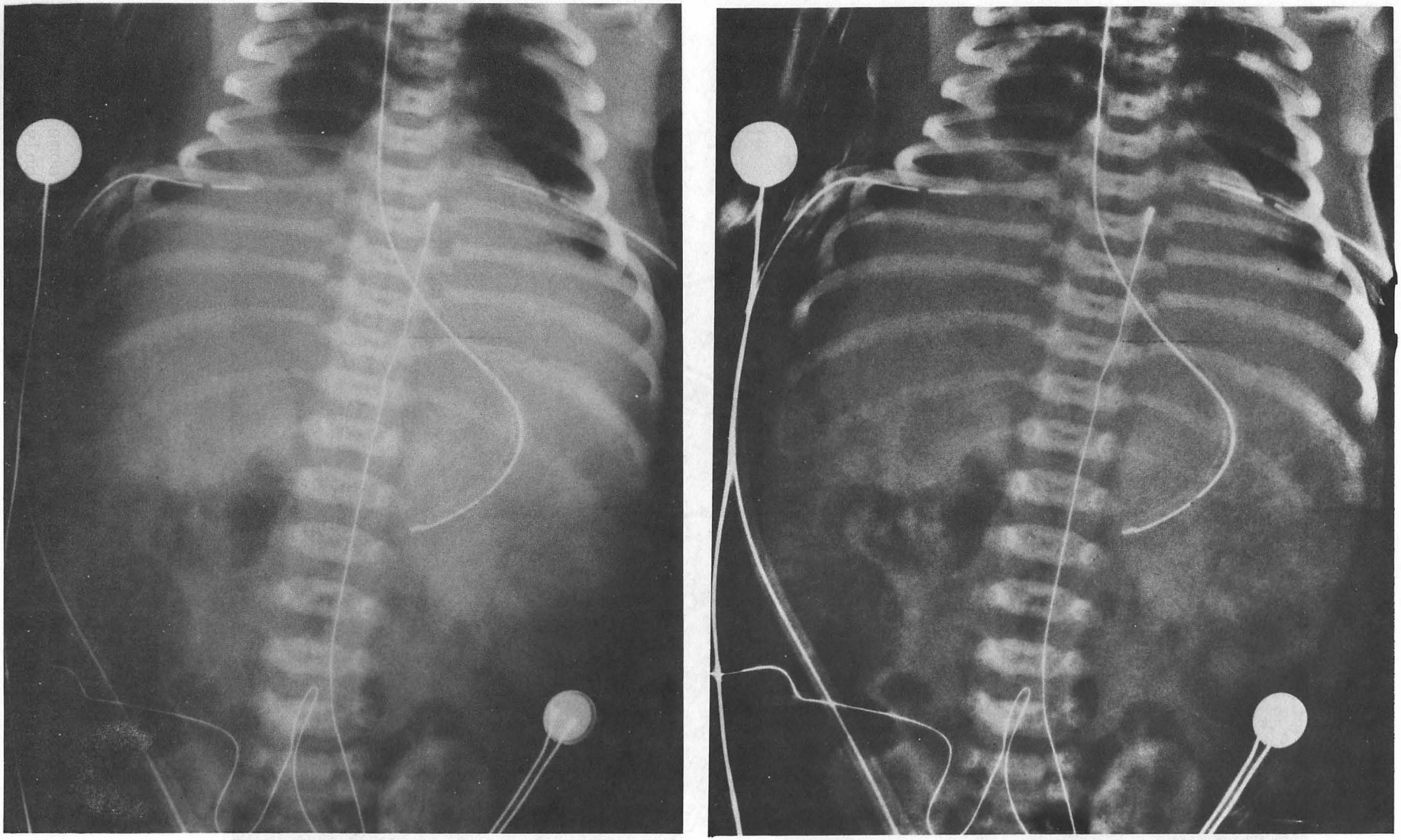


Figure 4. Pediatric intravenous pyelogram - polycystic kidneys -

4-a the original radiograph is underexposed

4-b the processed image reveals the renal outlines and shows a linear pattern in the renal parenchyma representing enlarged collecting tubules

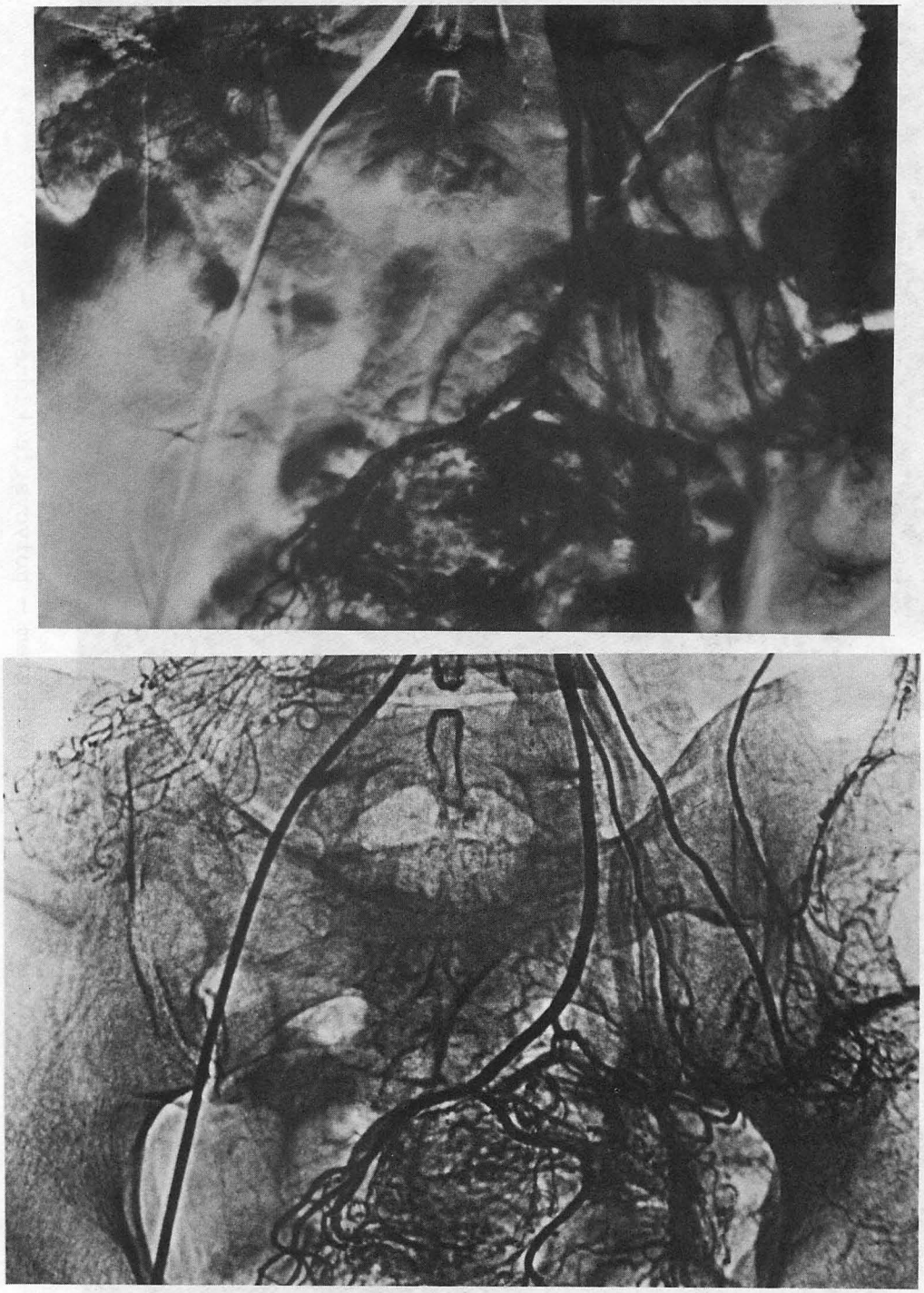


Figure 5. Celiac angiogram

5-a View over the pelvis done by film subtraction of pre- and post-injection radiographs

5-b Processed image made by contrast reversal (with some edge enhancement) from the past-injection radiograph only.

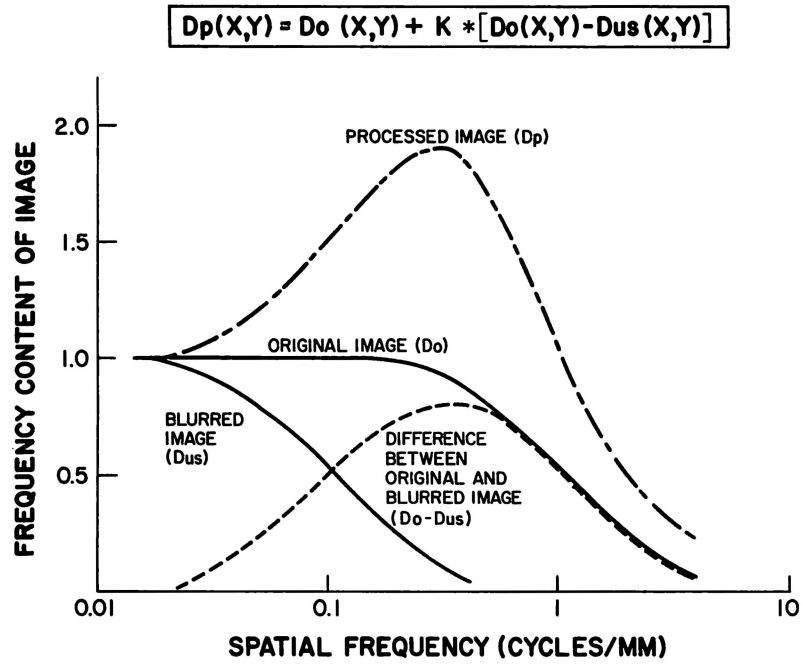


Figure 6. Diagram illustrating the effect of linear unsharp masking on the frequency content of an image

densities in some neighborhood of the point (x,y). Our program uses a weighting factor of unity for all points lying within a square or rectangle surrounding the point. The frequency content of the blurred image will fall off more rapidly than that of the original image, and a difference image formed by subtracting the blurred image from the original will have a frequency content which is nearly zero at both high and low frequencies. The frequency at which the content of the difference image is a maximum can be increased or decreased by making the size of the square neighborhood over which the densities are averaged smaller or larger, respectively. The difference image is multiplied by some constant, K, and added to the original image to form the final processed image. The amount of enhancement in the processed image will increase as the value of the factor K is increased.

This technique has an unfortunate property which it shares with

many other "sharpening" techniques. It enhances noise as well as anatomic structures. This is particularly bothersome in radiographs, which generally contain some low density regions. In these regions the number of x-ray quanta absorbed by the recording system is lower, and the quantum noise is relatively high. Therefore, application of linear unsharp masking as described above, tends to produce processed images which contain a distracting amount of enhanced noise in low density areas such as the lung bases or mediastinum in a chest radiograph.

To circumvent this difficulty, the amount of enhancement governed by the value of the multiplicative factor K can be varied according to the local density in the image. That is, K becomes a function of $D_o(x,y)$, and equation 2 becomes

3. $$D_p(x,y) = D_o(x,y) + K(D_o(x,y)) \cdot [D_o(x,y) - D_{us}(x,y)].$$

As shown in Figure 7, the values of this function are low for low density points and high for high density points. Accordingly, the amount of enhancement produced in high density areas of the film where there is relatively little noise is high, but little enhancement is utilized in the "noisier" low density areas. The difference between this nonlinear technique and the linear unsharp masking technique described above is quite apparent in clinical radiographs (Figure 8).

The processing system has been used in processing examinations such as mammography, tomography, and angiography, as well as for chest, double-contrast Gastro-intestinal, and bone radiographs. We include a few examples to illustrate the results. Figure 3 illustrates the recovery

LINEAR UNSHARP MASKING;

$$D_p(X,Y) = D_o(X,Y) + K * [D_o(X,Y) - D_{us}(X,Y)]$$

NON-LINEAR UNSHARP MASKING;

$$D_p(X,Y) = D_o(X,Y) + K_n[D_o(X,Y)] * [D_o(X,Y) - D_{us}(X,Y)]$$

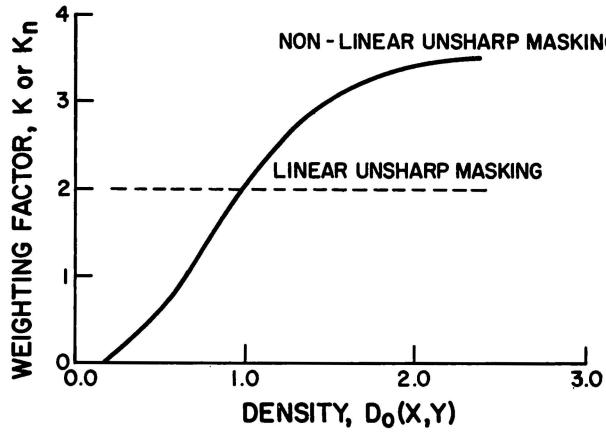


Figure 7. Weighting function (of film density) used in non-linear unsharp masking

of information from a badly overexposed hepatic arteriogram which has also been enhanced by non-linear unsharp masking using an averaging square measuring 3 x 3 mm. Figure 4 shows an underexposed intravenous pyelogram of an infant with polycystic kidneys and a processed image in which the grey-scale has been shifted. The characteristic enlarged tubules which are seen on the processed image are only faintly visable on the original radiograph - even in retrospect. Figure 5 compares a celiac angiogram done with photographic subtraction of the preinjection view to a grey-scale reversal of the digitized angiographic view alone which was simultaneously processed by unsharp masking. The processed digital image produces a similar or improved result, but does not require two exposures or a highly skilled operator to perform the subtraction. As a final example, mammographic images are shown in Figure 9. The pro-

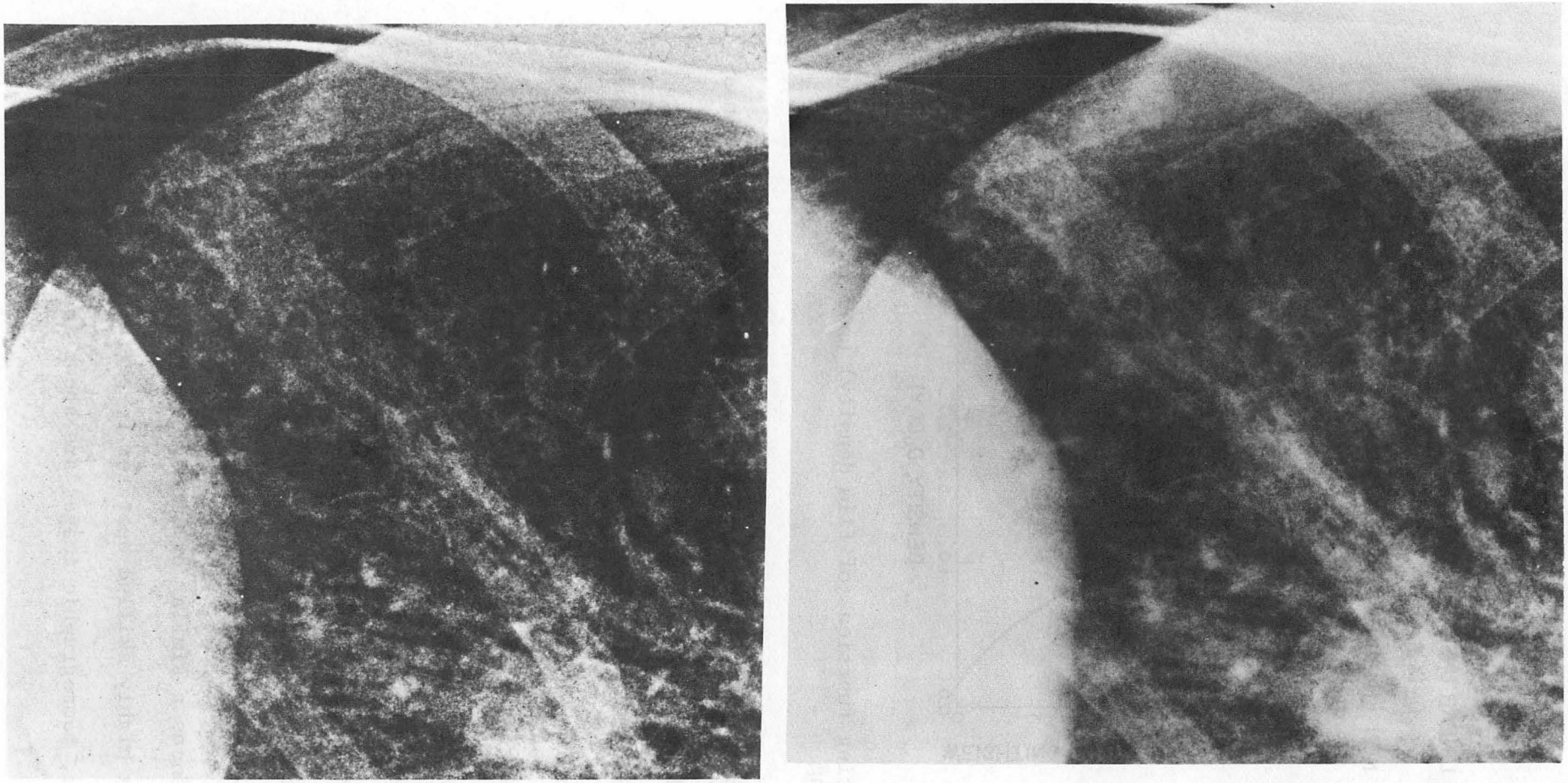


Figure 8. Portion of a chest radiograph in the region of the right lung base.
8-a Linear unsharp masking produces a noisy image.
8-b Non-linear unsharp masking produces a smoother image.

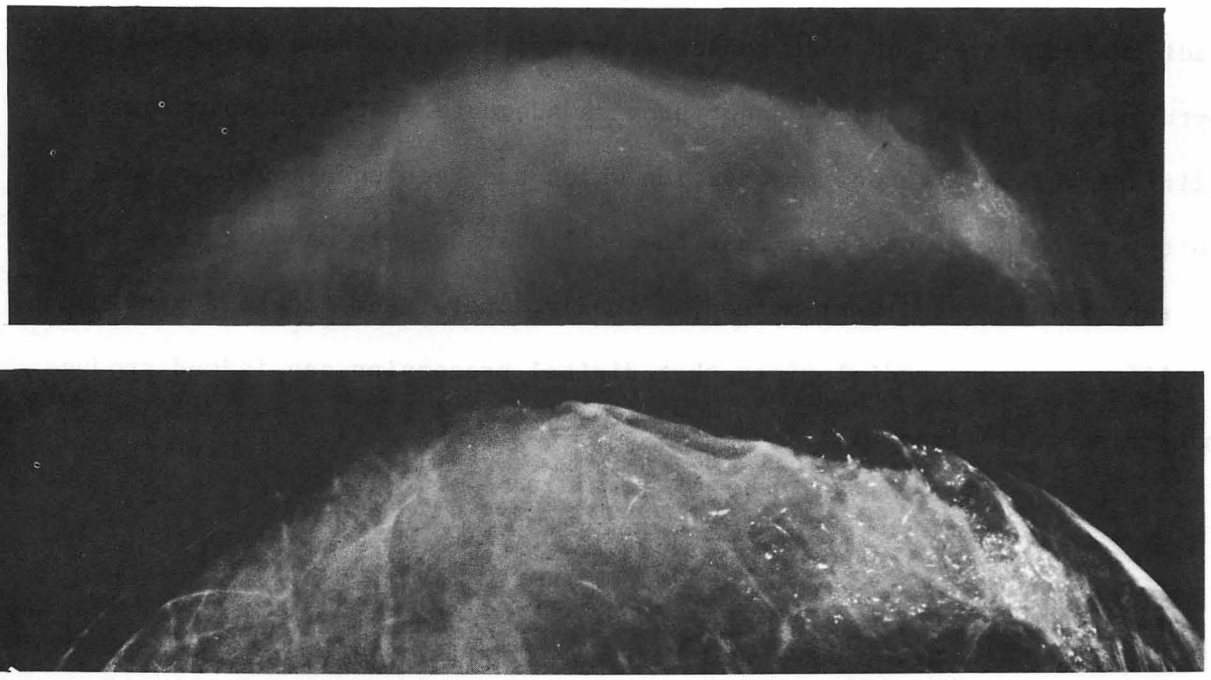


Figure 9. Mammogram
9-a Unprocessed radiograph in which the micro-calcifications are difficult to appreciate.
9-b Non-linear unsharp masking of the digitized radiograph brings out the micro-calcifications.

cessed image is enhanced by using an unsharp mask 3 mm in size. It is apparent on the processed image that there are multiple small calcifications which are characteristic of breast carcinoma. These are not seen as clearly in the original image.

CONCLUSIONS

The image processing system which has been described is located within our main clinical diagnostic radiology area. As a result, the flow of clinical images through the system has been more than ample, and we have gained considerable experience with the system's capabilities. Perhaps one of the most important conclusions we have reached is that the clinical quality of the digitized images appears identical to that of the original

radiographs. Even our most conservative radiologists have abandoned the myth that a digital image cannot provide adequate spatial resolution for clinical work. A second observation which has been unanimously agreed to by our clinical staff is that the nonlinear unsharp masking technique is superior to the linear method. Finally, there seems to be a growing feeling among our radiologists that digital processing can indeed produce more diagnostic images.

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DIGITAL FLUOROGRAPHY USING A GRAPHICS/IMAGE ARRAY PROCESSOR

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Introduction

Partly because of the limited availability of high quality commercial digital fluorographic systems, investigators in the Department of Radiology at the Hospital of the University of Pennsylvania decided to construct such a system from available commercial components. The design criteria centered around the concept of using a portable, versatile graphics/image array processor for such diverse imaging needs as ultrasound and digital fluorography.

System Description

Our digital fluorography system is diagrammed in Figure 1. Its principal components are the DeAnza IP5000 Image Array Processor, the Digital Equipment Corporation (DEC) LSI-11/02 computer, the DEC VAX 11/780 host computer, a fiber-optic data communication system based on Canoga Data Systems optical transducers, and the Siemens X-ray control and imaging equipment. Figure 2 shows this equipment in the angiographic room where it is utilized.

Image acquisition is under the control of the LSI-11/02. The LSI prepares the x-ray generator and initiates each exposure in the series. (The duration of exposure is manually set at the Siemens Gigantos

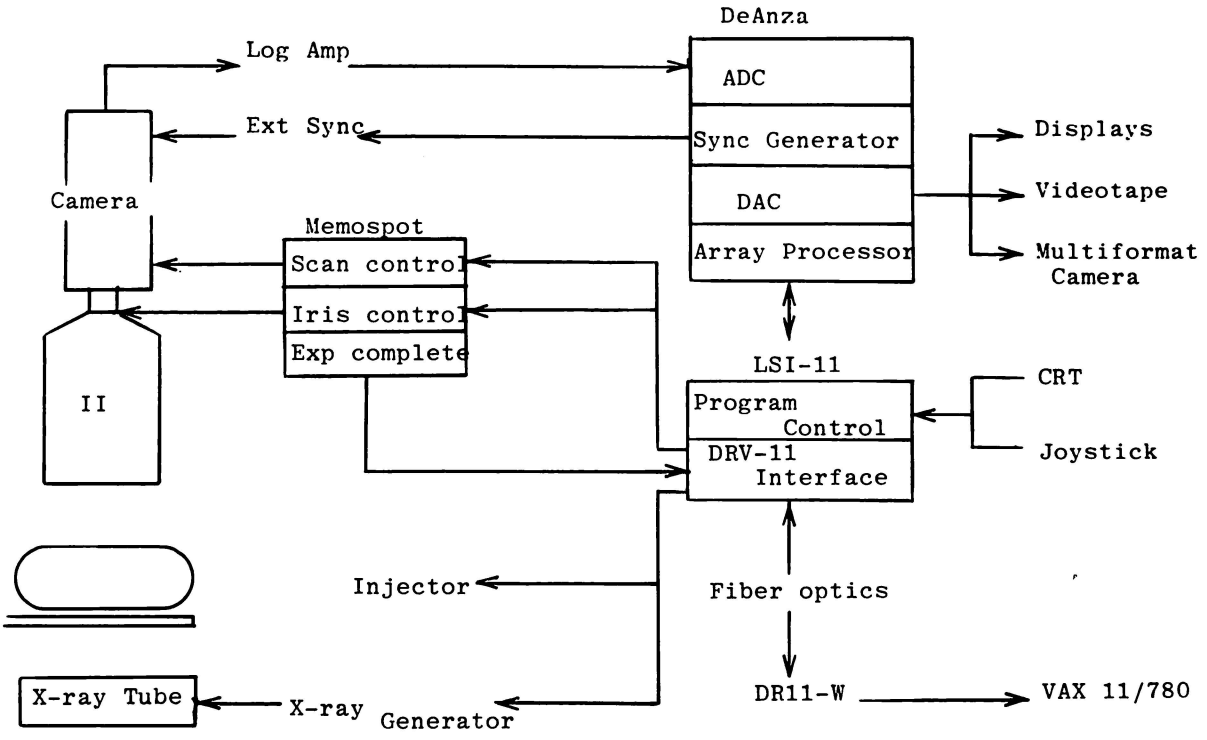


Figure 1

generator console.) As will be explained later, image acquisition can take place in one of two ways by controlling the scan signal to the television camera; this mechanism is also under LSI control. When the exposure is complete, a signal is sent from the generator to the LSI. The acquired image is then transmitted over the fiber-optic data link to the host VAX computer, where it is stored. Images are transmitted in real-time during the actual study, permitting acquisition rates of approximately one image per second. The fiber-optic network is the subject of another paper at this conference, and will not be discussed further here. A Winchester disk has recently been ordered for the digital fluorography system, permitting local image storage with transmission of image data taking place following the study. This should allow acquisition rates of approximately four images per second.

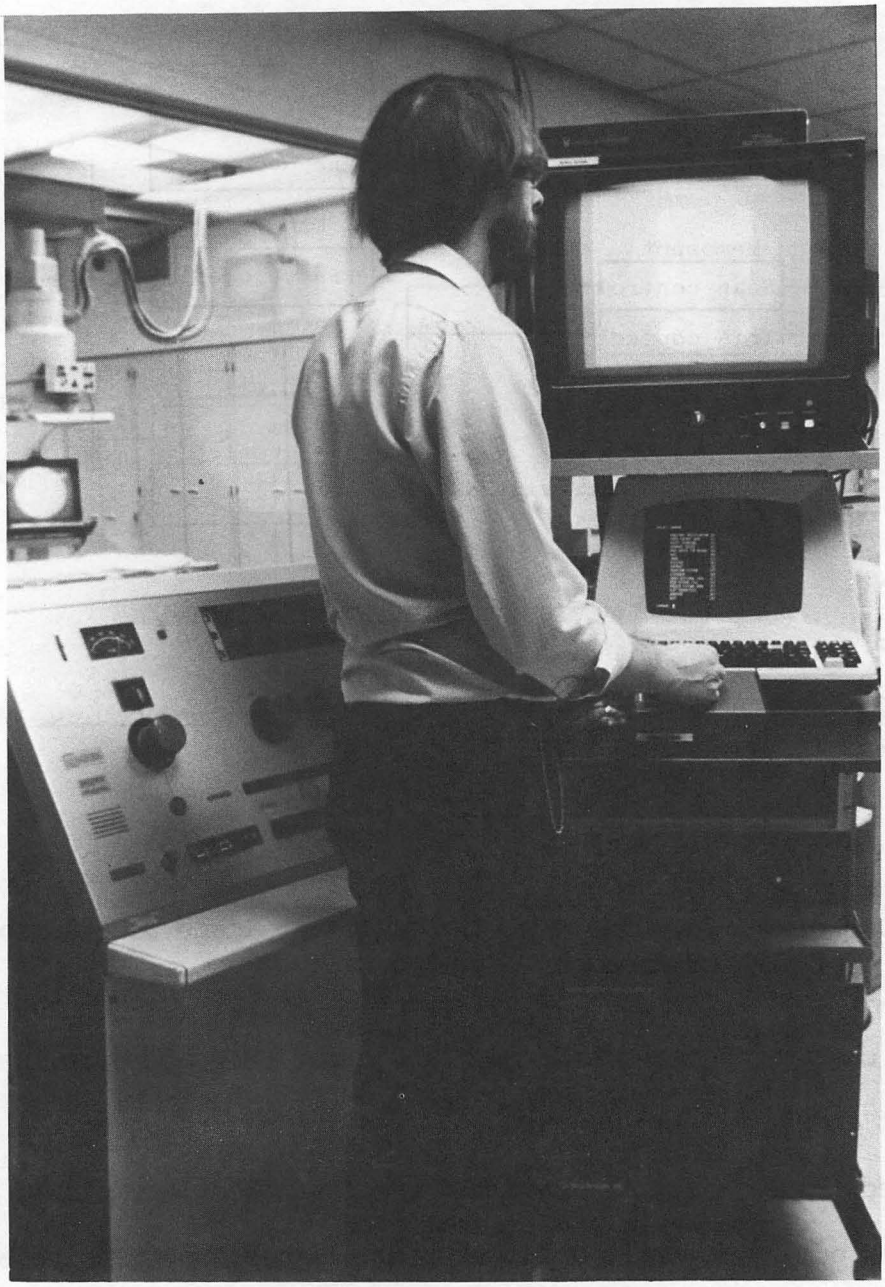


Figure 2

There is an iris for the image intensifier in the imaging system which is not controlled by the LSI, but rather by the Siemens X-ray control equipment. By adjusting the iris, a tradeoff can be established between the quality of the acquired image and the dose received by the patient.

The DeAnza Image Array Processor supplies the television synchronization signal for the Siemens camera, and digitizes the video signal from the camera via an 8-bit analog-to-digital converter (ADC). The digitized image is stored temporarily in a DeAnza picture memory prior to transmission. The camera operates in a 525 scan line mode; consequently, the resolution of the digitized image is 512x512 pixels by 8-bits deep.

A high degree of noise is present in image data acquired in a single camera beam scan of the face of the tube (1/30 of a second—one video frame). Two methods are employed to improve the signal-to-noise ratio (SNR). The first of these uses the LSI to inhibit scanning of the camera tube during exposure, as mentioned above. When exposure is complete, the camera beam is released and a video frame is captured. Since exposure times can be made longer than the time for one video frame, statistically the noise component is reduced as the image is accumulated on the camera tube.

This method does have one drawback, however. In our system, interlacing is employed in the camera scan system. Each video frame is broken down into two video fields, each having half the scan lines, each interlaced with the other. This approach reduces the flicker effect. Unfortunately, after the first video field of a video frame is stripped from the camera with illumination present (remember that the exposure is now complete), the second field is greatly diminished in intensity and is rendered unusable. Consequently, these images have a spatial resolution of 256 x 512, and alternate lines must be interpolated when

presenting the image. However, this tradeoff of spatial resolution for improved SNR may be reasonable and satisfactory; no conclusion in this matter has been reached yet.

The second method reduces noise by averaging four successive video frames together in the DeAnza, using two memory planes because the additional memory is required for the accumulation of carry bits. These four frames must be acquired during exposure; in addition, at least one frame time must be spent during exposure to allow for x-ray and camera latency. Consequently, the minimum exposure time for this technique is approximately 167 milliseconds. Note that the camera beam is not inhibited in this method. The resulting images have a true 512x512 resolution.

Once images have been stored on the VAX, they are accessible for recall and manipulation. Of primary interest is the subtraction of images from the same series, one image with and one image without injected contrast. It is not sufficient, however, merely to subtract the unprocessed images since x-ray attenuation in matter is exponential in nature. Iodinated contrast material appearing in a light region will not differ in intensity from the light region by the same amount as the same density of iodinated contrast appearing in a dark region differs in intensity from a dark region; this is because the attenuation is non-linear. In order to linearize the differences, the inverse exponential function, or logarithmic function, must be applied to the images before they are subtracted. This can be achieved in one of two ways, one being an analog technique and the other a digital technique.

Before image data are acquired by the DeAnza at the ADC input, it can be sent to a logarithmic amplifier for transformation. While this eliminates the quantization error present in digital techniques, it has several drawbacks. First of all, it introduces yet another stage of electronics, with its associated noise, into the video chain. Second, logarithmic amplifiers can be very unstable and frequently drift with fluctuations in temperature. Third, unsubtracted images are of necessity stored in a logarithmic form, since the transformation takes place prior to data acquisition by the digitizer and not subsequent to it. Digital logarithmic techniques present none of these problems.

The DeAnza Image Array Processor is used to provide logarithmic modification of image data before they are subtracted. Each 512x512x8 memory plane (one of which holds a mask, the other of which holds the image to subtract) is equipped with a look-up table (LUT) of 256 elements , each 8 bits wide. Each pixel from the input picture memory specifies a value from Ø to 255 (the range of 8 bits) and is used to specify an address for the LUT. The 8-bit value contained in this location then takes the place of the actual pixel value. If values representing a logarithmic transformation of input data are placed in the LUTs before subtraction, the desired effect will be achieved.

In reality, this process is complicated by another factor. Logarithmic transformations have the effect of stretching the increments between low values and compressing the increments between high values. In fixed point arithmetic machines, such as the DeAnza, this means that the input data, comprising 256 discrete values, will have fewer discrete

values when transformed (approximately 125), since some of the different input values will be mapped to the same output value. It is obviously desirable to maintain 8 bits worth of discrete values; if the DeAnza were equipped with LUTs that were 10 bits wide, then of the now available 1024 discrete values, approximately 245 would be preserved, which is very close to 8 bits worth of discrete values. However, the input values would still displace 10 bits, and a 10-bit subtractor would be required. The solution lies in the DeAnza's versatility. The LUTs are first loaded with the high-order 2 bits of a 10-bit logarithmic transform. The subtraction takes place and the result is placed in a third image memory plane. The LUTs are then reloaded with the low-order 8 bits of the 10-bit logarithmic transform. The subtraction takes place in order to adjust the high-order result by the borrowing of the low-order subtraction. Another subtraction then produces the low-order result, which is combined with the high order result and placed in the third memory plane. The entire procedure is executed in less than a sixth of a second.

The digital fluoroscopy system has in addition several useful operator functions, a few of which will be described here. A command is provided to allow the operator to locate a cross-hair on a "scout" image and generate from this a pixel intensity profile on a grid. (Figure 3) This enables the operator to determine the suitability of a pre-selected dose, which can then be modified if necessary to provide the broadest range of pixel values. Because patients will occasionally move during a series, subtractions can suffer from mis-registration artifacts. These problems can often be remedied by a command that allows the operator to

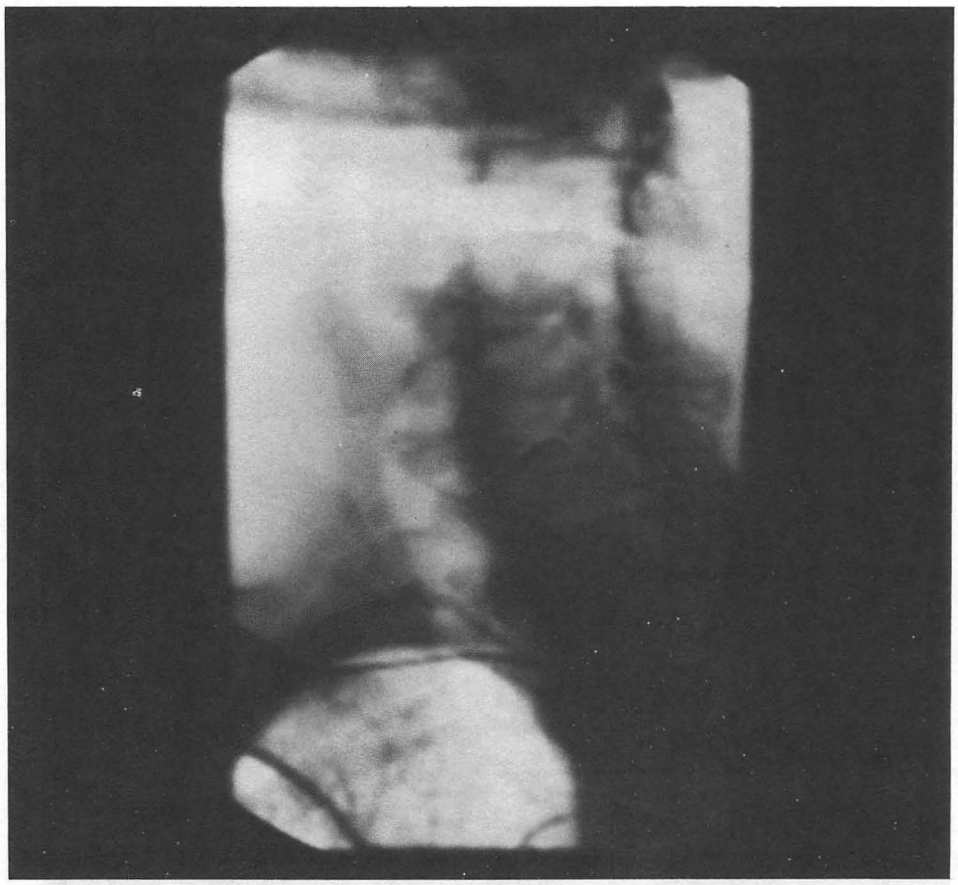


Figure 3A

re-register an image with the mask, thus cancelling a translation movement by the patient. Once the subtraction is complete, the operator can adjust the brightness and contrast of the result via a joystick control. If desired, the image can be inverted to present black on white instead of white on black.

These operator commands are initiated by selecting the proper function from the CRT menu (Figure 4). The joystick commands are prompted on the CRT to guide the operator.

One of the more salient features of the system is that it is



Figure 3B

completely transportable, being free for other image processing applications when not in use for digital fluorography. This imposes no limitation on image storage and retrieval, however, since the system has complete access to the central data base via the fiber-optic communication channel.

Clinical Use

Digital fluorographic systems are most commonly used to study carotid vessel disease. These intravenous angiographic studies may be

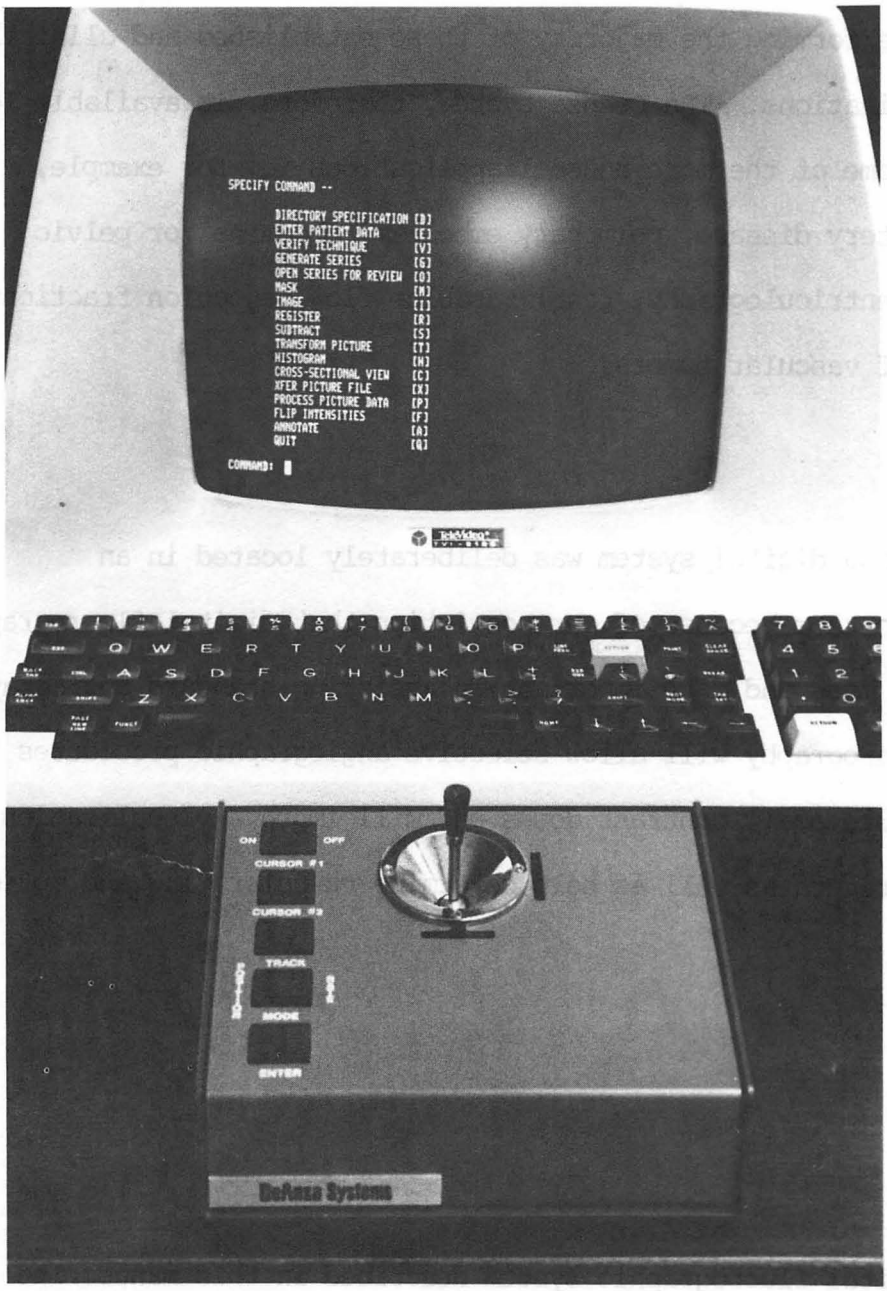


Figure 4

used for the evaluation of renal hypertension and abdominal aortic aneurisms; they may be used following vascular surgery and after angioplasties; they are also used for determining the patency of coronary bypass graphs. We are fortunate to have the prototype Diasonics digital fluorographic system. This new digital fluorographic

system is performing the majority of these established and clinically useful examinations. The DeAnza system, therefore, is available for exploring some of the more unusual applications in, for example, coronary artery disease, pulmonary embolism, abdominal or pelvic bleeding, ventriculography, renal vascular flow, ejection fractions, and the study of vascular tumors.

The DeAnza digital system was deliberately located in an angiographic room because of our conviction that digital fluorography will become more and more important in assisting standard angiography. Digital fluorography will allow selective angiographic procedures to be performed with small contrast doses and will improve visualization of the venous return as well as help determine vascular flow and motion.

Summary

The digital fluorographic system described in this manuscript is a versatile, portable, relatively inexpensive, and high-quality system. The extreme flexibility of this system has allowed frequent, relatively easy modifications both to enhance the overall performance and to investigate new applications and equipment.

A TRANSPORTABLE IMAGE PROCESSING SYSTEM FOR RADIOLOGY

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INTRODUCTION

Image processing, especially based on digital technology, has emerged from modest beginnings to a major research and development area (1-5). The influence of 1-dimensional signal processing research (6-8) on 2-dimensional (9) image processing is great, especially in linear systems (10,11) and global image operators.

The importance of digital image processing in medicine is recognized when we consider modern diagnostic imaging systems, including computed transaxial tomography, digital ultrasound (gray scale B-mode and real time scanners), digital intravenous angiography and future picture archiving and communications systems.

To a significant degree, digital image processing techniques can be implemented in software on a conventional minicomputer with display memory and applied to a wide variety of image types. The same processing algorithms for image metrication, enhancement and restoration may be applied without modification to photographs, micrographs, radiographs, ultrasound and CT scans, and scintigrams.

In order to determine appropriate image processing algorithms for a wide spectrum of medical images, a transportable image processing software system for medical image enhancement and analysis has been developed. The system, the Mallinckrodt Institute of Radiology Digital Image Processing System (MIR-DIPS), operates

on a 28K 16 bit minicomputer (PDP-11) or a virtual memory 32 bit minicomputer (VAX-11/750). The system supports a variety of elementary image processing functions, especially those involving local operators.

The system has several notable features: A very broad spectrum of images may be handled with relative ease, including plain radiographs, photographs, ultrasound B-scans, CT scans of the head and body, scintigrams, and cineradiographs. No specific knowledge of computer programming is needed to operate the program. The system is largely coded in a machine independent dialect of ANSI Basic FORTRAN, and can be transported to a foreign hardware environment with considerably less effort than required to implement the same algorithms originally. The system is extensible, new commands can be added by coding the appropriate subroutines and adding, deleting or modifying entries in the tables used by MIR-DIPS. The system is menu oriented, so that the choice of legal commands at any point in the operation of the program is evident to the user. The system will support a display memory subsystem, if one is available. Support for an array processor (Floating Point Systems FPS-100) is included to expedite computational procedures.

General System Description

The Mallinckrodt Institute of Radiology Digital Image Processing System, MIR-DIPS, was originally designed and implemented on a minicomputer (DEC PDP-11/34) system under a single user

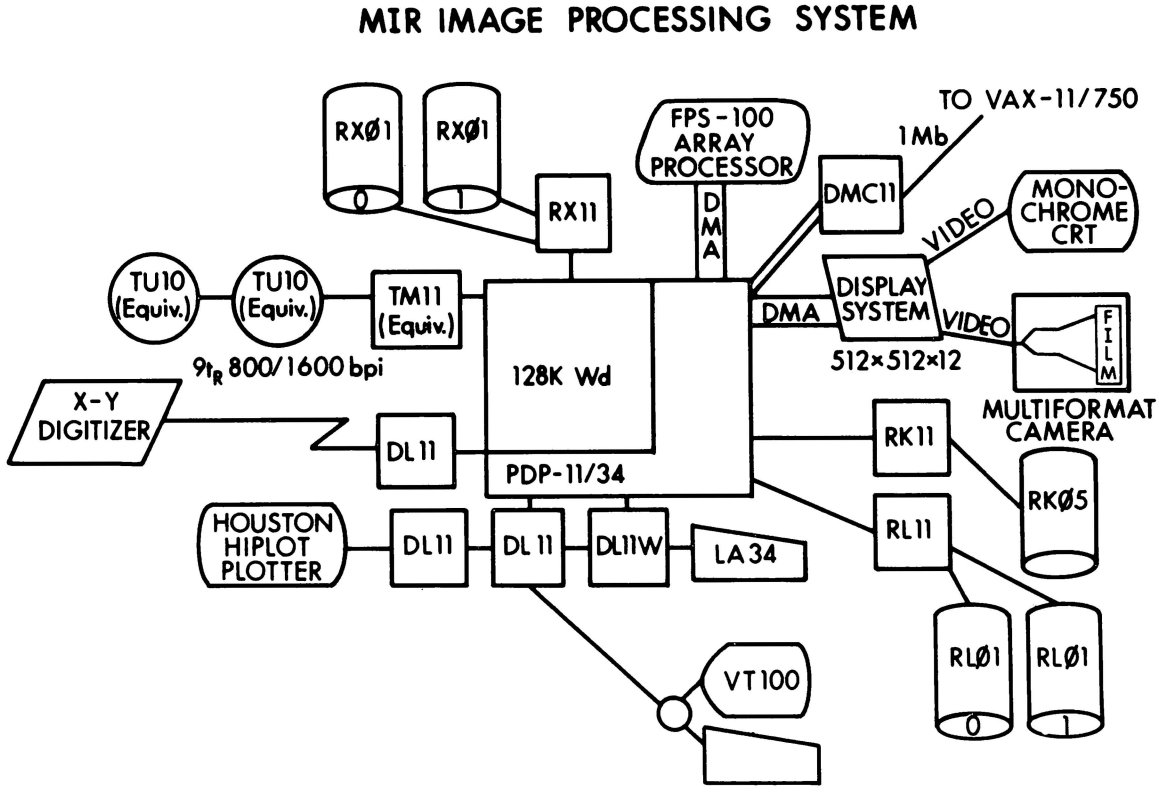


Figure 1. - Configuration of single user minicomputer system for digital image processing.

(RT-11) operating system (Figure 1). Source coding was done largely in a subset (ANSI Basic Fortran) of Fortran/RT-11, and to facilitate transportability care was taken to avoid hardware, operating system, and dialect specific code. The MIR-DIPS system image processing subroutines typically exist in overlays and are machine independent. Machine dependent input/output subroutines are few in number, and conversion to different hardware and software configurations consists largely of recoding these subroutines, recompiling and linking the MIR-DIPS source code with these I/O routines.

Several unusually powerful function processors are incorporated

in the MIR-DIPS system. These include histogram modification, discrete convolution, magnification with Lagrangian or bilinear interpolation, median filtering, and a variety of image arithmetic functions.

The system requires 28K words of memory (56K bytes) for operation on a PDP-11, using the RT-11 single job monitor. This program is divided into multiple overlays with a root segment and two subsidiary levels. No special arithmetic hardware is required, but a hardware floating point processor can be readily utilized, should one be available.

The MIR-DIPS software for the PDP-11 consists of 55 user written subroutines and a main program. A simplified version, 100% coded in PDP-11 Fortran, is available. A much faster version with several subroutines recoded in PDP-11 Macro assembly language has also been implemented. The MIR-DIPS software system consists of approximately 12,000 source statements. A total of 22 overlays are used in the RT-11 version of MIR-DIPS.

Display Memory Subsystem

The MIR-DIPS software is designed around a 512x512 pixel display memory with 8 to 16 bits per picture element. A smaller display memory, for example 256x256, could be utilized with minor modifications. The display system used with the RT-11 version of MIR-DIPS is a DeAnza Systems, Inc. Model ID-5512/8C with DMA inter-

face (512x512 pixels with 12 bits per pixel, 10 bits of intensity data and 2 graphics overlay bits for region-of-interest). Individual pixels, lines or parts of lines may be read from or written to the display memory.

Image data files are 512 or fewer lines in length. Each line contains 512 pixels, from 8 to 16 bits in length. When 8 bit picture data is written to the display memory, the 8 bits of gray scale are shifted left 2 bits to assure maximum significance in the 10 bit per pixel gray scale memory of the DeAnza display subsystem.

Many different methods exist for bringing a new image into the display memory. First, the user may choose to read the input data file making use of the maximum transfer rate of the input device (usually a cartridge disk drive) and the DMA output to the display memory. This is accomplished with the "NEW" command (Table 1).

Alternatively, the user may elect to input the data from disk using Fortran direct access I/O, typically in a format other than 512 bytes per line. This is accomplished using the "INput image from disk" command.

If an image already exists in the display memory, and the user wishes to overlay the present image with one stored on the disk, he may choose to add the images, subtract one from another, or to load the input image into a selected range of bits in the

MALLINCKRODT INSTITUTE OF RADIOLOGY

DIGITAL IMAGE PROCESSING SYSTEM

MIR-DIPS VERSION 1.3

19-APR-82

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Figure 2. - System identification on startup may be displayed on the image display monitor (PDP-11 version) on VT-100 CRT terminal screen (VAX-11 version).

10 bit per pixel intensity data. The later function is useful for obtaining misregistration data that can be used in a geometrical spatial warping procedure to align image pairs.

User Interface

The command language for MIR-DIPS is readily mastered by inexperienced computer users, and no knowledge of computer programming or even image processing is needed to utilize the system. After starting the system (Figure 2), a general menu (Figure 3) is displayed (Table 1). The user may choose any desired image processing function by typing the first two characters of any legal menu item. The menu is then erased, and a secondary menu (Figures 4,5,6 or 7) is displayed (Tables 2,3,4 and 5).

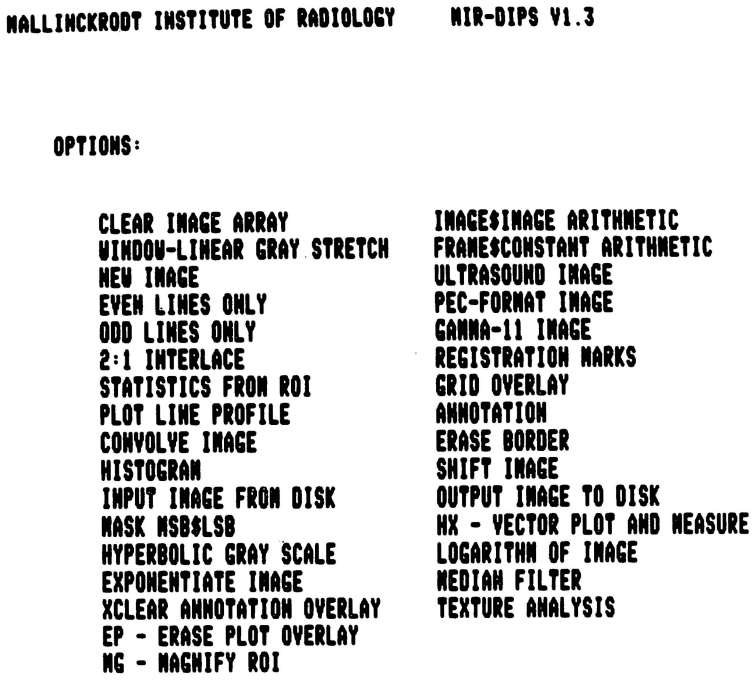


Figure 3. - Main system menu for image processing software system (Table 1).

The user may choose a desired function from the secondary menu, and the MIR-DIPS system will perform the function he selects on the image presently stored in the display memory. When the function is complete, the primary menu (Figure 3, Table 1) is again displayed.

Display Window

The "WI" or window function brings a secondary menu (Table 2, Figure 4) offering a wide variety of contrast modification possibilities. These functions are implemented through interactive adjustment of the intensity transformation table (in the DeAnza ID-5512 display system) using a joystick. The window limits, least upper bound (LUB) and greatest lower bound (GLB), are displayed

TABLE 1 - PRIMARY MENU

Option	Definition
CLEAR IMAGE ARRAY	Erase the display memory, plot overlay and character overlay.
WINDOW	Modify the display window (intensity transformation table) and center using joystick. Activates the display window processor. The secondary menu, "MONOCHROME INTENSITY TRANSFORMATION MAP" is displayed.
NEW IMAGE	Load a new image into the display memory from a disk file (512x512x8 bits input format).
EVEN LINES ONLY	Disable display interlace, show even lines of image.
ODD LINES ONLY	Disable display interlace, show odd lines of image.
2:1 INTERLACE	Enable 2:1 interlace on the display.
STATISTICS FROM ROI	Operator selects a region of interest (ROI) using the joystick and cursors, and statistics are calculated and displayed (max, min, mean, avg, area).
PLOT LINE PROFILE	The gray scale profile from a selected line of the image is plotted using a graphics overlay bit of the display memory. Optional hardcopy plot can be obtained.
CONVOLVE IMAGE	Activates the discrete convolution processor. The secondary menu, "CONVOLUTION PROCESSOR" is displayed.

Option	Definition
HISTOGRAM	Activates the gray scale histogram processor. The secondary menu, "HISTOGRAM PROCESSOR" is displayed.
INPUT IMAGE FROM DISK	Asks the user to specify an image input data file and image format. More flexible than the "NEW IMAGE" command. Uses Fortran Direct Access I/O.
MASK MSB & LSB	Masks off a selected number of the most significant or lest significant bits of each pixel.
HYPERBOLIC GRAY SCALE	Histogram hyperbolization routine. Modifies each pixel by dividing by its complement or vice versa.
EXPONENTIATE IMAGE	Replaces each pixel by a scaled exponential of the original value.
XCLEAR ANNOTATION OVERLAY	Clears the annotation overlay in the display memory. (Used for photography).
EP - ERASE PLOT OVERLAY	Erases the graphic overlay bits of the display memory.
MG - MAGNIFY ROI	Magnifies a selected region of interest by bilinear or Lagrangian interpolation.
IMAGE & IMAGE ARITHMETIC	Combines the image presently stored in the display memory with an externally stored image by adding, subtracting, multiplying or dividing the pair. Scaling is provided.
FRAME & CONSTANT ARITHMETIC	The image presently stored in memory is combined with a scalar constant by addition, subtraction, division or multiplication.

Option	Definition
ULTRASOUND IMAGE	Reads an ultrasound B-scan image into display memory from a floppy disk created on a Picker 80L-DI B-mode scanner.
PEC - FORMAT IMAGE	Reads an image (typically a radiograph, cineradiograph, or photograph) that has been digitized on a Perkin Elmer scanning microdensitometer.
GAMMA - 11 IMAGE	Reads a nuclear medicine image (scintigram) in DEC GAMMA-11 format from a disk or mag tape file into the display memory.
REGISTRATION MARKS	Places a regular array of tic marks over image by writing a pattern into a graphic overlay bit of the display memory. These marks are used to judge the approximate misregistration error in pairs of images, or to estimate distances.
GRID OVERLAY	Overlays the image in the display memory with a grid pattern, with grid lines at 50 pixel intervals.
ANNOTATION	Permits the operator to annotate the image being displayed by entering character sequences that are placed in the character overlay of the display memory. These comments are used for photography.
ERASE BORDER	Erases a border with an optional width from the image stores in the display memory.

Option	Definition
SHIFT IMAGE	Translates the image in display memory by a selected number of pixels in the x and y directions.
OUTPUT IMAGE TO DISK	Transfers the contents of the image memory to disk or mag tape in a selected format.
HX - VECTOR PLOT AND MEASURE	Permits the operator to specify the end points of a vector in any orientation using the joystick and cursors. The length of the vector and location of the end points are reported.
LOGARITHM OF IMAGE	Replaces each pixel with a scaled logarithmic transform of the original value.
MEDIAN FILTER	Filters the image using a rectangular median operator as specified by the operator.
TEXTURE ANALYSIS	Computes the gray scale transition matrix (GSTM) and statistical moments for use in texture analysis and pattern recognition experiments.

numerically adjacent to the intensity transformation scale (at the right hand side of the display image).

MIR-DIPS For The VAX-11

The MIR-DIPS software system has been transported to a virtual memory midicomputer (DEC VAX-11/750) under the VMS operating system. The sources were recompiled and linked without overlays

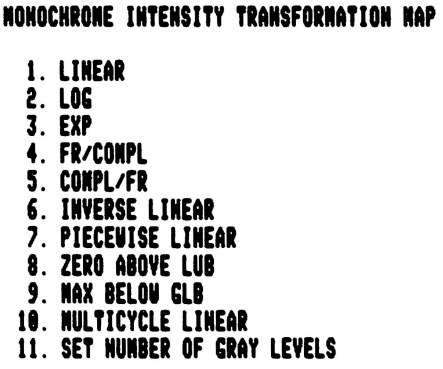


Figure 4. - Monochrome intensity transformation table menu (Table 2).

on the virtual memory VAX-11 system. System specific commands to operate a CRT terminal (DEC VT-100) for display of the menu functions in the MIR-DIPS system were incorporated.

The migration of the MIR-DIPS software to the VAX-11 environment (Figure 8) is significant in several respects. First, the VAX-11 supports multiple users and emphasizes resource sharing. Therefore, many users can be supported with different types of medical imagery in remote locations, all using the same software system. Each user operates his own copy of the program, and all users can share the same image data base.

Second, the VAX-11, in its current configuration, does not have a display memory system of its own, such as the DeAnza display on the PDP-11 system. Nevertheless, images can be transferred through the MIR digital imaging network for processing under MIR-DIPS software control. The display memory is simulated in the user's own virtual memory on the VAX-11. Each user has his own virtual display memory which can be loaded with image data, mani-

TABLE 2 - MONOCHROME INTENSITY TRANSFORMATION MAP

1. LINEAR	Straight line interpolation between gray scale limits. White above LUB, black below GLB.
2. LOG	Logarithmic scale. White above LUB, black below GLB.
3. EXP	Exponential gray scale transformation. Opposite of LOG between GLB and LUB.
4. FR/COMPL	Hyperbolic transformation (Frame/ Complement). Typical multiplier is 125.
5. COMPL/FR	Hyperbolic gray scale transformation (Complement/Frame). Typical multiplier is 125.
6. INVERSE LINEAR	Straight line interpolation from white to black from LB to UB. White below GLB, black above LUB.
7. PIECEWISE LINEAR	User-defined piecewise linearly interpolated gray scale transform.
8. ZERO ABOVE LUB	Linear gray scale with black level above LUB.
9. MAX BELOW GLB	Linear gray scale with white level below GLB.
10. MULTICYCLE LINEAR	Overflow cycles (user specifies number of cycles) with linear interpolation.
11. SET NUMBER OF GRAY LEVELS	User may define number of gray levels from 2 to 256.

NOTE: UB = Upper Bound LB = Lower Bound

GLB = Greatest Lower Bound LUB = Least Upper Bound

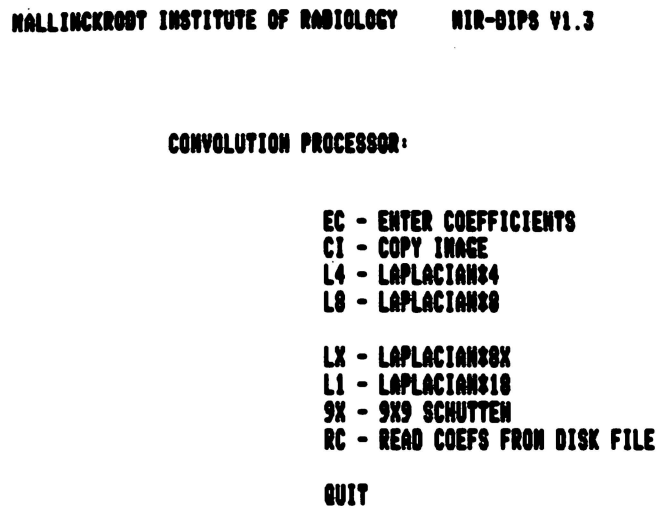


Figure 5. - Two dimensional image convolution operator menu (Table 3).

pulated using the standard commands, and then the results can be stored on the VAX-11 disk drives. The image stored on the VAX-11 can be transferred to specific imaging systems that are interfaced to it. In fact, each user may operate several copies of the MIR-DIPS software using the VAX/VMS "SPAWN" and "SUBMIT" commands, so that batch operations and off-line processing is supported, as well as interactive image processing.

Processed Image Storage

At any time in the sequence of image processing procedures, should the user desire to save the processed result, the contents of the display memory can be written to disk or tape. Once stored on disk or tape, the processed image may be accessed at a later time in the same fashion as an unprocessed image.

TABLE 3 - CONVOLUTION PROCESSOR

Option	Description
EC - ENTER COEFFICIENTS	Requires the operator to manually enter the value for the coefficients in a 2-D convolution operator. These coefficients may be integer or floating, symmetric or asymmetric.
CI - COPY IMAGE	Convolves the image with a degenerate operator (1x1). Used for test and timing purposes.
L4 - LAPLACIAN*4	Four point Laplacian operator. Used for unsharp masking procedures.
L8 - LAPLACIAN*8	Eight point Laplacian operator.
LX - LAPLACIAN*8X	Variant of 8 point Laplacian, with a slightly different operator.
L1 - LAPLACIAN*18	5x5 Laplacian operator with 18 non-zero coefficients.
9X - 9X9 SCHUTTEN	High pass filter, 9x9 operator, originally described by Schutten. Used for image detail enhancement.
RC - READ COEFS FROM DISK FILE	Inputs a 2-D convolution operator from a disk file. In general, this is used to apply a filter which has been designed using the 1-D FIR design program and 2-D transformation described in the text.

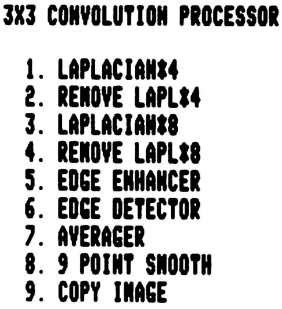


Figure 6. - Local 3 x 3 convolution with integer coefficients, menu of kernel options (Table 4).

Convolution Processor

Several discrete convolution operators (Tables 3 and 4, Figures 5 and 6) are provided with the system. The user also has the option to design a discrete convolution operator to meet desired specifications. An interactive adaptation of a popular Fortran program (9,12,13,18) for the design of optimal discrete finite impulse response digital filters with equiripple stopband characteristics (Chebychev Type II) including single or multiple bandstop designs, Hilbert transformers and differentiators, is included in the MIR-DIPS system.

The system may specify the filter type and characteristics and a suitable design will be calculated. The 1-dimensional coefficients may then be converted to a 2-dimensional design using a McClellan transformation (13), basically a change of variables procedure. This 2-dimensional operator can be applied to the image stored in the display memory by a discrete 2-D convolution process. Applications of this procedure include image segmentation, edge enhancement, smoothing and many others (14-17,19).

TABLE 4 - 3X3 CONVOLUTION PROCESSOR

1. LAPLACIAN*4	4 point Laplacian operator, including vertical and horizontal neighbors but not diagonals.
2. REMOVE LAPL*4	Unsharp mask based on a 4 point Laplacian operator.
3. LAPLACIAN*8	8 point Laplacian operator, including all neighbors of a pixel.
4. REMOVE LAPL*8	Unsharp mask based on an 8 point Laplacian operator.
5. EDGE ENHANCER	Weighted local operator designed to emphasize edge detail.
6. EDGE DETECTOR	Weighted local operator designed to extract local edges.
7. AVERAGER	9 point average of a pixel and its 8 neighbors. Equal weights.
8. 9 POINT SMOOTH	9 point weighted local average of a pixel and its neighbors.
9. COPY IMAGE	Degenerate convolution operator with zero weights except for central pixel. Used for testing and timing procedures.

Further improvements in execution speed were realized by incorporating an array processor (Floating Point Systems, Inc., FPS-100) in the RT-11 based PDP-11/34 system. The array processor provides a floating point execution speed improvement of between 100 and 200 times for the discrete convolution operations described

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HISTOGRAM PROCESSOR:

PH - PLOT HISTOGRAM
EQ - EQUAL PROBABILITY TRANSFORM
GS - GAUSSIAN STRETCH

QUIT

Figure 7. - Gray scale histogram processor, menu of options (Table 5).

above. Prior to the use of the FPS-100 array processor, discrete convolutions with symmetric 9x9 floating point operators required approximately 3 hours on our PDP-11/34 (which does not have a floating point processor). Less than 3 minutes are now required for a larger operator using the array processor.

A secondary menu (Figure 6) for 3x3 neighborhood convolution operations is available using the array processor. These local operators (Table 4) are non-adaptive in their design and implementation.

Histogram Processor

The gray scale histogram is a powerful tool for global image contrast modification. The central position of the gray scale histogram in monochrome digital image enhancement was described by Andrews (14). We have implemented a histogram processor which measures and may modify the distribution function (Figure 7, Table 5).

TABLE 5 - HISTOGRAM PROCESSOR

Option	Description
PH - PLOT HISTOGRAM	Computes the gray scale histogram and plots it using the graphics overlay of the display memory or on hardcopy.
EQ - EQUAL PROBABILITY TRANSFORM	Computes the equal probability transform of the image stored in the display memory, and replaces the original image with the transformed result wherein all gray levels are equally likely.
GS - GAUSSIAN STRETCH	Modifies the gray scale histogram to approximate a gaussian shape.

The gray scale histogram may be computed and plotted for the image stored in the display memory. The frequency distribution of image gray levels, the monochrome histogram, contains from 256 to 65,536 elements (corresponding to 8-16 bits per pixel) of 8 bits per element in the MIR-DIPS software. This vector may be determined (PH command) and plotted in soft or hardcopy form as a cumulative or frequency distribution.

If all gray levels are equally probable, the global image contrast will be maximum. This transformation is implemented in MIR-DIPS as is the gaussian gray scale stretch, a modification which forces the gray scale distribution to approximate the normal curve.

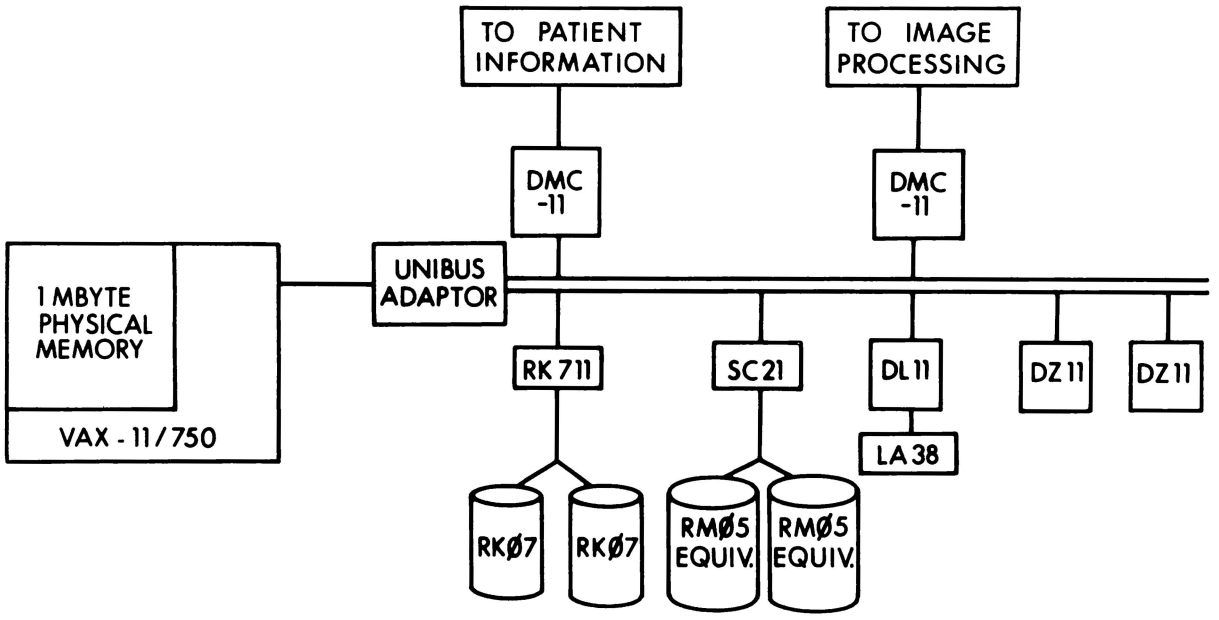


Figure 8. - Virtual memory midicomputer (VAX-11/750) system configuration.

Applications

This image processing software system has been used in the analysis of a variety of diagnostic imagery. Two samples of its use will serve to exemplify this issue.

In a digital vascular imaging (DVI) study of the aortic root and coronary arteries, a sequence of fluoroscopic images was obtained with a DVI system (Siemens Digitron). The 256x256 images were transferred to MIR-DIPS in raw unprocessed form (Figure 9a). To improve the perceptable detail in the image, unsharp masking was applied by a local Laplacian convolution operator (Figure 9b). Contrast enhancement was applied to the unprocessed frame by global histogram equalization (Figure 9c). Both detail and con-

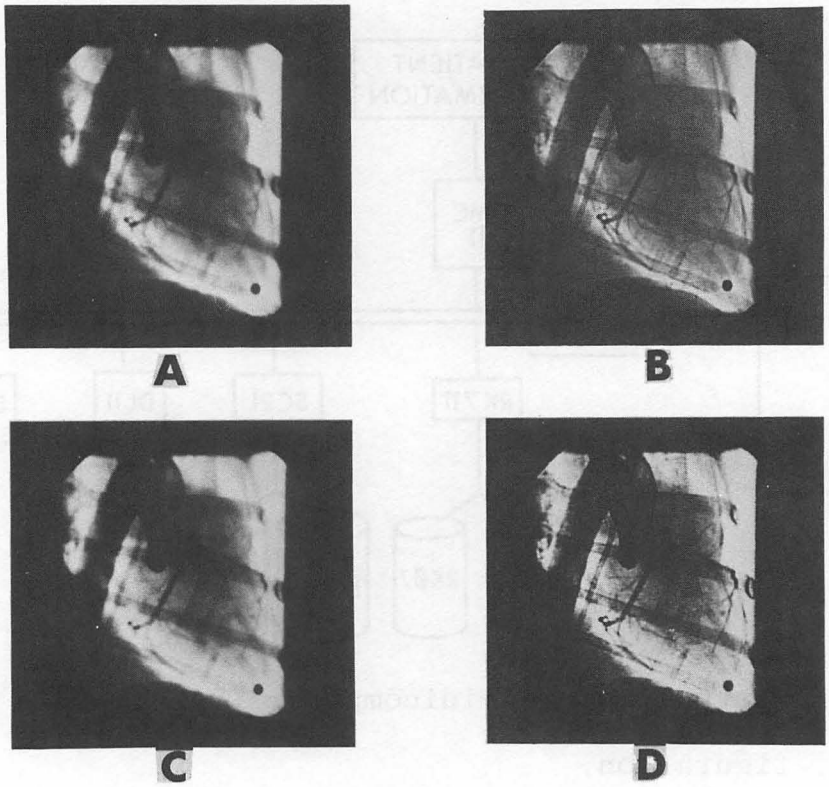


Figure 9. - Canine coronary arteriogram obtained with a digital vascular imaging system (Siemens Digitron). Aortic root injection of 10cc contrast (MD 76).

A. Original unprocessed image (256x256 matrix).

B. Unsharp masked image, edge enhancement using a 3 x 3 Laplacian operator.

C. Contrast enhanced image, global histogram equalization processed result.

D. Contrast and detail enhancement by unsharp masking and histogram equalized.

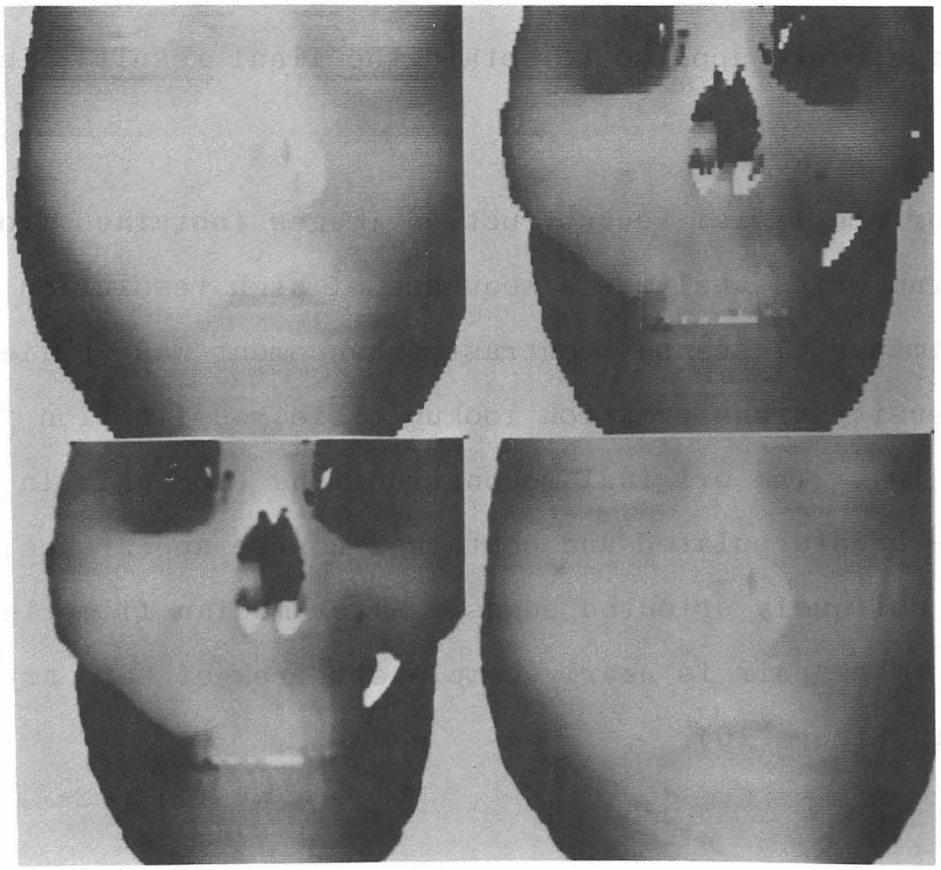


Figure 10. - Three dimensional facial reconstruction from a patient with polyostotic fibrous dysplasia. These images were produced from analysis of a contiguous set of narrowly collimated (2mm) CT scans.

Upper Pair - Original 3-D reconstructed surface images for soft tissue and bone. Note the irregular "digital" appearance, especially at obliquely oriented edges.

Lower Pair - Same as above except median filtered. Note the improved appearance, particularly at oblique edges.

trast enhancement were applied to obtain the final result (Figure 9d).

In the surface facial reconstruction images (obtained from a separate program which analyzes a sequence of high resolution narrowly collimated CT scans), contrast enhancement was applied using the intensity transformation lookup table modification functions (Figure 10). The original reconstructions (top pair in Figure 10) are uninterpolated and contain a coarse appearance, especially at obliquely oriented edges. After median filtering, the processed image pair is nearly completely free of this artifact (bottom pair in Figure 10).

Conclusion

A transportable digital image processing software system was designed and implemented. The system is functional on both a minicomputer (PDP-11) and virtual memory midicomputer (VAX-11). The system is transportable, extensible and interactive. Such a system provides a method for evaluating a wide variety of image processing algorithms, and when linked to a digital image distribution network, can serve as an image processing laboratory for radiology images gathered throughout the department.

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QUALITY ASSURANCE OF MEDICAL COMPUTER SYSTEMS

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ABSTRACT

As long as computers remained simply an auxiliary device which served as a backup or augmentation to the routine clinical testing the lack of quality control was not a serious medical or legal problem. However, in recent years the computer has become a primary diagnostic tool, with other instrumentation performing the role of backup. Evidence of this is seen in the use of computers for cardiovascular studies in nuclear medicine and in the introduction of digital radiographic processing. As a result of this increasingly central role, it is important to quantify the effects of hardware and software parameters in the clinical study and to implement methods by which routine monitoring can be performed. General comments and suggestions can be made concerning common hardware systems, but it is much more difficult to make meaningful suggestions for specialized hardware. Software has as much to do with the diagnostic output of a patient study as does the hardware used to make the initial measurements. The effects of software reliability or accuracy

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will eventually have an impact on the confidence of clinicans and research associates.

This paper discusses a general approach to the quality assurance of medical computer systems. The computer system is divided into software and hardware sections. Recommendations are made concerning the acceptance of new software packages as well as techniques for ongoing monitoring of software operation. The hardware is approached from the standpoint of system operation rather than testing of the individual components. The environment of the computer is also addressed because of its impact upon the reliable operation of the system. At the present time, it is not clear what would constitute practical and worthwhile quality assurance procedures in many instances. However, the problem must be addressed and not allowed to lie neglected until it represents a significant threat to the quality of medical care.

INTRODUCTION

Computers have been used for a long time in the clerical operations of the health care profession. However, in recent years they have become a more central part of the actual health care delivery system. Their presence was perhaps most keenly felt in the introduction of the transmission computed tomography systems in 1972. Since that time they have gained an important place in the performance of nuclear cardiology studies and even

more recently, in digital radiography. Although computers are important in these applications they are also found in varying degrees of sophistication in less visible areas of medicine. They are now an integral part of cardiac monitoring stations and critical care facilities where they are used for on-line monitoring of patient vital signs.

In spite of this widespread and increasingly central role in the health care delivery system, there has not been a significant expression of concern by users about the quality assurance of medical computer systems. This apparent lack of concern probably arises from several sources, not the least of which is the widespread tendency on the part of busy people to ignore potential problems until they become actual problems. There is also a tendency on the part of many users to regard computers as different from other types of instrumentation. Computer based instruments are often tinged with an aura of infallibility (an attribute which is often enhanced by the salesman's attempts to sell) as well as with a hint of mysticism about the exact details of their operation. A surprising number of even very sophisticated users tend to treat the computer and computer based instrumentation as "brittle systems". That is, they believe that any failure in the hardware will bring the system to a halt and that it would be impossible to operate with faulty hardware. This may have been true in many primitive systems but present day hardware designs are such that many

hardware failures can remain undetected for extended lengths of time unless they are looked for by the user.

The complexity of computer based instrumentation further complicates the question of quality assurance testing and evaluation. The versatility of equipment whose functions and operation can be altered by software changes make definitive testing very difficult. Often the system is constructed from general purpose hardware and software modules which can sometimes be isolated from the rest of the modules and tested individually. However, more often than not, this ability to test the individual components is lost once the entire system is assembled and placed in operation in the clinical environment. Not only is the ordinary user unable to test the individual components, the service personnel, who hopefully have a higher degree of technological skill, are often also unable to test at this level, because of lack of special test equipment. For this reason, it is important that meaningful test procedures be devised which can be used to imply the correct operation of the subassemblies, while not requiring direct testing methods.

It must be emphasized that it is not the responsibility of the clinician, nurse or clinical technologist to determine what specific component is malfunctioning. This should be the responsibility of the service technician or engineer. The tests that would be performed by the clinical personnel should be first designed to indicate correct system operation and only

secondly be concerned with identifying the individual failed component.

Testing procedures and protocols can be divided into three classes. These are: 1) confidence testing, 2) quantitative evaluation, and 3) maintenance diagnostics. The first class of testing procedures are simple tests that answer the question "Does the system seem to do what it is supposed to do?" Examples of this in practice are the performance of the water phantom scan in a CT scanner, collection of a test image in a nuclear cardiology system, or simply the observation that a cardiac monitoring system is indicating the same heart rate as is obtained by manually taking the patient's pulse. This type of test does not provide a quantitative indication of the absolute correctness but simply gives one confidence that the system is not seriously impaired.

The second class of tests are those that provide the quantitative indication of correct operation. These tests should be performed at system installation to completely characterize the system and then periodically throughout its life to monitor drifts and alterations in the operating characteristics. These tests would be performed less often than the simple confidence test but would provide more detailed information about the system and its subassemblies. Examples of such tests would be count rate response measurement in nuclear cardiology computers, spatial resolution and noise levels in CT images and sensitivity

adjustments in cardiac monitoring systems. These tests may be performed by the technologist or the routine operator of the equipment but more often will be performed by a service technician or ancillary support engineer.

The third class of tests are the maintenance diagnostics. Although these are included here, they are not strictly quality assurance tests. They are tests that are normally run by service engineers in an attempt to ascertain the location of a specific failed component or to assure that a repair has had the desired effect. These tests are mentioned here only because they have been suggested by some vendors as quality assurance procedures. As stated below, the author of this paper does not agree with this. Maintenance diagnostic programs really have very little application in the clinical environment and should not be considered as user tests.

It is not sufficient simply to quantify the effects of hardware and software parameters in clinical studies, as is done during an acceptance testing procedure. It is perhaps more important to implement methods by which routine monitoring of the various parameters can be performed. This is necessary to prevent changes in hardware components, changes in study protocols or changes in software from producing undetected changes in clinical results. In many present day applications of computers, patients undergo initial studies at the beginning of a clinical workup and then are periodically studied during

the course of clinical treatment. If at some point in the treatment schedule, the analysis system drifts, then it is obviously impossible to determine whether changes in the patient results are the product of the equipment drifts or the treatment.

As stated earlier the quality control of computational systems can be an extremely complex problem. However, the problem can be somewhat simplified by dividing the "computer" problem into a "hardware" problem and a "software" problem. Although it is impossible to make this division clear and complete, it is possible to arbitrarily seperate the problems even though there is a very fuzzy overlap area. The hardware portion of the problem is perhaps the easiest to understand because it represents something concrete and physically present in the room. Also, the concept of quality assurance of hardware is well accepted in almost every branch of medicine in which technology plays a significant role. The evaluation of software, especially semi-automatic, image processing software (e.g., automatic edge finders) is much more difficult and its solution is much less clear cut. The rest of this discussion will divide the computer system into these two major subject areas.

SOFTWARE

Software can be divided into four catagories:

1) Operating Systems

2) System Subroutines

3) Maintenance Diagnostics

4) User Application Programs

The first three of these are usually supplied by the system vendor, while the fourth is implemented by the user, who sometimes also contributes special routines to the system libraries represented by catagory two. All software should also be divided into two other groups, i.e., "under development" and "complete and in routine use". Unfortunately, the division between these groups is often unclear and all too often one finds a third class--"under development and in routine use".

There often is an attitude that software once developed and debugged never fails. To a certain extent this is true but there are a number of factors which affect software's ability to perform correctly.

Any operating system that is being actively supported by its vendor will undergo periodic updates. These ranges from small patches which the user inserts in the existing system to wholesale replacement of the entire system. While the small patches are normally issued to fix errors which have been discovered in the system and are relatively minor, the system must be tested after the patch is performed in order to determine that is has been properly installed, as well as that

it doesn't alter existing program operation. This is best done by running analysis programs with standard data sets. The replacement of the entire operating system is another matter. Quite often the new version incorporates all of the patches issued for the old as well as implementation of new options. It is not unusual for many of the library routines to be rewritten to provide faster or enhanced execution. The installation of the new operating system often requires the user to recreate the load modules used to run the collection and analysis programs. In this case, it is imperative that all programs be tested before they are used on patient data.

Software under development is an area which requires very tight quality control to ensure that a program designed to perform a given analysis or control function does in fact perform that function when implemented. Included in this class of software are not only new programs but also old established routines to which the "answer" is not known a priori. It is difficult to ensure proper operation. All too often proper operation is assumed after the analysis of one or two sets of patient data produces answers that seem right. Programs used to process simple in-vitro data are relatively easily verified because it is usually possible to generate a data set which accurately simulates true data and for which the answer is known. Image processing routines, such as those used for nuclear medicine cardiac function analysis, are more difficult to

verify. In this case, the application of the program to data generated via a phantom study can provide some confidence in its correctness. The use of patient data is the strongest assurance. In any case, all failures of the program following its incorporation into routine use must be investigated immediately to determine the cause of the failure. It might be a result of a fault in the program or it may be an anomaly in the data which wasn't considered when the program was designed.

One area of quality control often overlooked is the maintenance of the integrity of patient data bases. This includes the individual studies which are conducted for patient followup, as well as the large amalgamated bases which produce statistics from a large number of studies. Data bases are collected and saved for a variety of reasons, among which are research (efficacy studies, clinical correlation, numerical analyses) and administrative management (indexing, retrieval, reporting, billing). For routine daily access to data bases, they are usually stored on the device with the fastest access time, i.e., on disk, as opposed to magnetic tape. As data bases are created, the total number of entries is often small and there is a normal tendency to not worry about what happens if the disk file or the disk itself gets destroyed. Unfortunately, it is also often the case that this tendency to ignore possible catastrophy is allowed to continue until the file is too big to be manually reentered, at which time a "nothing has happened yet,

why worry" attitude takes over. If the data base has any value at all, it is worth protecting. The minimum protection that should be enforced is the periodic creation of a seperate copy of the file on another disk. For systems without other media, such as tape or floppy disk, this is all that can be done. A better protection is periodic copying to another media, such as from disk to magnetic tape. Periodic examination of the data base is necessary, at a frequency dependent on how often it is updated. During this inspection, one should determine if the data entry protocols are being followed and if the file is changing in any way due to system errors, i.e., whether numbers are changing because of erroneous disk transfers, whether there are dropped bits, etc. The point about entry protocols can be important in long term projects in which several different data entry personnel are used over a period of time.

HARDWARE

Although a computer is often considered a "brittle system", in which any hardware failure, no matter how small, will bring the entire system to a crashing halt, it is possible for failures to go undetected and produce anomolous results. There are two ways to protect oneself against such failures. The simplest is to routinely run critical analysis programs using a fixed data set to ensure that expected results are produced. The second is to routinely run hardware diagnostics on all the system components. While this latter method may seem a more

elegant approach, it is not necessarily the most effective one. Also, in systems with components from several different manufacturers, one may not have good diagnostic routines for all the system parts. Another difficulty is the fact, well known among hardware experts, that hardware diagnostic programs only determine whether or not the diagnostic runs and not whether the user's software will run. It is virtually impossible to duplicate all the timing and I/O operations of a user program with a diagnostic and so one can only test a representative set of operations. The diagnostic program does give one some confidence in the hardware but it is by no means a guarantee of continued operation of an applications program. Thus, the first technique of routinely running a standard analysis would be preferred for quality control.

Because of the widely varying areas of application of computers in medical and clinical science, it is difficult to propose specific testing procedures that are universally applicable. Perhaps a more appropriate approach for a general discussion such as this is the proposal of some general guidelines along which to design the controls and tests. One thing that must always be born in mind is that the end user in the clinic, i.e., the physician, technologist or basic scientist, is not really interested in the fact that any single component is functioning properly. What the end user is really interested in is, "Is the system as a

whole operating as expected or desired?" As stated above, it is virtually impossible to design a test that guarantees that the system is 100% fault free. The best that can be done is to test the system in such a manner that one has some degree of assurance that it is providing reliable and explainable results. Clinical laboratories perform their quality assurance along these lines when they periodically process samples for which the results are known. Often they also process multiple samples from the same patient sample. Consistancy or lack thereof is an indication of the proper system operation. Note that agreement between the multiple samples does not guarantee that the results are correct. They may all be wrong by the same amount, hence the need for samples with known answers.

The present use of computers in computerized tomography, digital radiography, and nuclear medicine represents a class of systems in which, although the computer is a large portion, there is a significant amount of non-computer hardware. In this case, it is virtually impossible for the user to uncouple the various portions of the system for quality assurance testing, even if one so desired. Thus, any testing the user can perform must include large sections of this peripheral hardware. The collection of uniformity images in nuclear medicine and scans of water phantoms in CT are forms of confidence tests that provide assurance that the system as a whole and not just the computer, is functioning properly.

Quality assurance testing is done for two reasons. The testing discussed so far, both for software and hardware, has been aimed at the determination of correct operating capabilities. The second reason for quality assurance is that it can often allow one to predict failures and schedule repair and readjustment before the actual failure. The ability to do this in the clinical environment is extremely important.

One difficulty with digital systems is that, with the exception of physical failures in the construction, i.e., loose screws, corroded contacts, etc., the systems rarely fail in an intermittent fashion. Nor do the digital electronics fail in a gradual fashion, as do analog circuits, which may require periodic readjustments. For this reason, the performance of memory diagnostics, I/O bus tests and such examinations of the hardware provide little or no information about potential future failures of the system.

The prediction of failure, especially in the auxiliary instrumentation, is quite often possible with the use of the computer. Periodic examination of critical paramters such as spatial linearity, sensitivity, ADC conversion gains, power supply voltages, display brightness, etc., can provide one with the capability of detecting slow, long term drifts for which scheduled maintenance can be arranged. Knowledge of parametric drifts such as these can allow one to compensate for them in clinical techniques and therefore provide better diagnostic and

therapeutic care.

ENVIRONMENT

Because of the complexity, initial cost, and repair expense, the quality control of the environment in which the computer operates should be included in ongoing quality assurance programs. If the environment is neglected and allowed to become too hot, too dry or too dirty, no amount of quality assurance testing and measurement will assure continued high quality operation.

Environmental considerations must include temperature, humidity, power supply and, as noted above, cleanliness. Room size considerations relate primarily to adequate work space, adequate space for servicing, storage of disks and tapes, and the storage of hardware and software manuals. Computers require controlled and stable levels of room temperature and humidity. In general, it can be said that what is comfortable for the operator of the system will be comfortable for the system. A temperature of 70° and a relative humidity of approximately 50% is ideal. Low humidity in a computer room can cause static electricity which, other than being annoying, can actually cause the computer to fail. Because of the density of electronics in the modern computer the temperature often is 20° to 30° higher inside the computer than in the room. For this reason, it is very important that the room temperature be maintained at a

comfortable level. Operating for extended periods of time at high room temperature can cause serious damage to the electronics which may become evident later as intermittent failures and generally unreliable operation.

Variations in room temperature and humidity will affect not only the mainframe computer operations but will also affect the integrity of all magnetic storage media. Magnetic tape will stretch with increased temperature, and moisture condensation may occur on disk platters which have been moved from cool environments. It is a good practice to store all the magnetic media in the rooms with the same environment as the computer. The dimensional requirements of modern disk and tape drives make the small dimension changes caused by temperature changes important to the reliable operation of the system.

CONCLUSION

The quality assurance of computers in diagnostic and therapeutic medicine has not received the attention among the general user community that the level of computer use would seem to warrant. This is probably due in part to the lack of substantial guidelines from vendors and other suppliers of hardware and software. It is also partly due to the fact that naive users often have the mistaken impression that the computer will always fail in an obvious manner--because it is a digital system and will either operate correctly or it will not operate

at all. As the computer and related equipment, in the form of microprocessor controllers, become more central to the performance of diagnostic and therapeutic procedures, this neglect of quality assurance can no longer be tolerated.

It is unclear at the present time what would constitute practical and worthwhile quality assurance procedures in many instances. But the problem can not be allowed to lie neglected by the user community or the supplier community until it represents a significant threat to the quality of medical care. It must be remembered that quality assurance is not so much the routine performance of a prescribed set of tests as it is the maintenance of an attitude of alertness to potential problems and failures in the systems being used.

EVALUATING THE IMPACT OF A COMPUTERIZED RADIOLOGY INFORMATION SYSTEM

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INTRODUCTION

In a radiology department, one of whose primary functions is to produce information frequently essential to medical diagnosis and treatment, the impact of a system to computerize the processing of that information is likely to be substantial. The goal of introducing such a system is to bring positive change to the department, usually expressed in such terms as "increased efficiency", "better patient care", "improved service" and the like. How can one be certain that the changes wrought by this complex, expensive tool are, in fact, positive and of the magnitude anticipated? One approach is to formally evaluate the system's impact on the department in a controlled manner.

At least two types of evaluation can be applied to a computerized information system. One evaluates the system itself--whether or not certain functions are performed and how well; whether or not the hardware and software function in the manner prescribed. The other focuses on the system's impact on it's environment--whether or not the system is producing the desired results; how well personnel interact with the system; what kinds of positive, negative and unanticipated results are generated. This study concerns itself with the latter focus, although the two are not completely separable. By evaluating the performance of a manual information processing system in a radiology department, and comparing the results with a

subsequent evaluation of a computerized information system, this study attempts to determine the nature and extent of the impact of the automated system on selected aspects of department operations. This paper outlines and discusses the design of that study and presents some preliminary results.

THE SETTING

Harborview Medical Center, in Seattle, is one of two University of Washington teaching hospitals. The Department of Radiology, where this study is set, is responsible for all inpatient and outpatient radiographic studies in four sites: a main department, a trauma center, and satellites in orthopedics and urology. A full range of exams, including ultrasound and tomographic studies, is conducted in the main area. The trauma area is responsible for trauma portables and non-portables, as well as for inpatient portable exams. Trauma also provides all radiology coverage on evenings and weekends. During the initial phase of this study the department was conducting an estimated 150 to 200 exams per day, of which approximately two-thirds were in trauma and one-third in the main department (including a small number of orthopedic exams). This study was initiated by the department's decision to computerize its information system.

STUDY DESIGN

In the simplest of evaluation designs one merely observes the impact or outcome of an event after it has occured. This kind of evaluation is often called a "one-shot" case study. The

limitations of this design are fairly obvious, i.e., one cannot be certain of the nature or magnitude of the changes wrought by the event. There are no benchmarks against which to compare one's observations, nor can one be certain that the effects observed are not due to something other than the event being studied.

One can improve on the one-shot study by adding another observation point preceding the event. The first observation, or pre-test, gives one the baseline data against which to compare the results of the second observation, or post-test. Provided that one conducts both tests in the same manner, one should be able to gauge the nature and magnitude of the changes brought on by the event.

A refinement of the two-test design which allows one to control for the effects of external events or influences is the use of a comparison (control) group of subjects. If the two groups are nearly identical, except for exposure to the intervening event, any observed differences in the pre-test/post-test comparisons of the two groups are likely to be due to the effects of the event itself. For the Harborview study, a comparison group is used in one of the five segments, as discussed below.

Another method of monitoring external influences, particularly if they are seasonal in occurence (such as rotation schedules of medical residents), is to repeat a series of

evaluations over time. This time-series evaluation method also allows one to assess the longer-term stability of the observed effects of the event--not possible with a single post-test. A drawback of the time-series method is the extra planning, time and expense that numerous observations require.

In the Harborview case study, some forethought regarding an evaluation of the computer system's impact led to our ability to use the pre-test/post-test design. Thanks to an early interest by the administration at Harborview and support by the U.S. Bureau of Radiological Health, enough lead time was available to plan, design and administer a controlled observation of the radiology department's manual information processing system prior to the installation of the computer system.

An important consideration in using the pre-test/post-test design is the timing of the observations relative to the event. The pre-test should not precede the event too closely, lest the observations be influenced by activities conducted in preparation for the event. In the case of a computer installation, such activities may include facility changes to accommodate hardware or meetings held to orient the staff to the forthcoming changes. Neither should the pre-test be conducted too far in advance of the event, thus allowing time for intervening, unanticipated events to occur. A reasonable elapsed time between pre-test and the start of installation of a computer system would probably be within a range of six to nine

months.

Similarly, the post-test should not follow the event too closely. If one is to evaluate the system's impact accurately one must allow a reasonable period to elapse to assure that its components are functioning properly and that the appropriate personnel are knowledgeable regarding its use. Too early a post-test may measure the impact of a system that is not functioning at its expected level--nor with the same benefit of familiarity as the system observed in the pre-test. Again, one does not want to wait too long before conducting the post-test, although this is not as great a concern. Depending on the complexity of the new system and the degree of change which it introduces, one may wish to wait from six months to one year following completion of the installation before initiating the post-test.

METHODOLOGY

Having determined that the installation of a computerized information system at Harborview represented a good opportunity for a before-and-after evaluation, it was necessary to determine which areas of potential impact to evaluate. A review of the radiology department's objectives for the system yielded five areas of study that were of particular interest to the department, the evaluation team and the Bureau of Radiological Health. Those five areas are: (1) timeliness of reporting; (2) availability of management information; (3) unbilled exams; (4)

attitudes regarding the department; and (5) changes in departmental costs. The first three examine anticipated direct effects of the new system: a decrease in information processing time, an increased availability of information and a reduction in the number of unbilled exams. The other two areas monitor more indirect consequences: changes in attitudes and costs.

For each of the five areas of study an evaluation protocol was designed to obtain the data required in as economical and non-disruptive a manner as possible. Each is discussed in turn, below.

1. Timeliness of Reporting

The objective in this case is to measure the amount of time required to complete each of the steps involved in the radiology examination and reporting process. At Harborview that process can be conveniently divided into component activities, beginning with the patient's arrival and culminating with the radiologist's signature on the written report. The key in this study was to find a way of accurately recording the time taken by each activity. Two possible methods were suggested. One would involve posting observers with timepieces at various stations. An alternate method, selected for the study, involves having the department staff record times on standardized recording forms. While this process might artificially slow the exam and reporting processes by a few seconds, the fact that the

same process is followed for both the "pre" and "post" observations should serve to control for any effect on the results. This method does have the advantage of being easier to administer, less intrusive, and less costly than posting observers.

The most persuasive argument for using staff reporting forms in this study was ease of administration. The department's manual information processing system relied on a multi-part requisition form which accompanied the patient, exam films and report through the entire information processing system. By attaching a time recording form to each requisition for a sample of patients, we could therefore assure that the opportunity would exist for the processing times to be entered.

The instrument used was a one-page typewritten form requiring department personnel to enter the times at which certain activities were initiated and completed. For example, a technologist would enter the time at which an examination began; and the time at which the films were transferred to the file room to be processed. Other information was requested regarding the types of exams performed and whether or not the patient had previously been seen in the department

Two major concerns in the design of this portion of the study were accuracy and compliance. In order to explain the purpose and the necessity for their accurate completion several one-half hour training sessions were held for all those who

would encounter the form during the two week sample period. During each session the form and its instructions (which were printed on the reverse side of each form) were reviewed, and staff were encouraged to ask questions about the form and the study. Excellent cooperation was received in this process from supervisory personnel in the department.

One time-recording form was attached to each requisition for patients seen in the main and trauma areas during a two week period. Prior to data collection, synchronized digital clocks were placed at each station where times were to be recorded. At the end of the two weeks a total of 1680 forms had been completed, 497 from the main department and 1183 from the trauma area. Department records show a total of 2043 exams for those two weeks, so actual compliance was approximately 82 percent.

For the main department the total average time to process the requisition, from the patient's arrival until the signing of the final report, was calculated to be just under 11 days. The bulk of that processing time was found to occur after the exam was completed and the patient released. In other words, the most time-consuming activities were the matching of films with files and the dictation, transcription, review and signing of the report.

In the trauma area, the average total processing times were calculated for three different categories of exam: trauma portables, non-portables and inpatient portables. The average

times were respectively; eight days, six and one-half days, and slightly under nine days. As in the main area the lengthier processing times involved activities related to the production of the written report.

It should be noted that the radiographs are available for review and discussion with a radiologist before dictation, transcription and signing. Regular, scheduled review of inpatient radiographs by the clinician with the radiologists is a usual prerequisite to dictation, and is the forum for exchange of information and opinion. In the trauma area their review and conference takes place even before matching of films with files. Thus, the written report serves to document the examination results, but is usually not the primary vehicle for communicating them.

2. Availability of Management Information

For this portion of the study, the objective is to assess the extent to which various hospital personnel have ready access to different kinds of information needed to perform their jobs. These jobs involve patient care, management, teaching and research.

Addressing this objective involved a series of steps, the first of which was to review the existing manual information processing system. This investigation involved on-site inspection of operations, interviews and the review of forms used by the Radiology Department for communication, transfer and

storage of information.

The second step reviewed relevant documents describing the expectations for the computerized information system: Harborview's request for proposal for the system, documentation for the certificate-of-need process and the system vendor's proposal. These documents were reviewed to abstract all pertinent expectations and proposals for the enhancement of information availability with the computerized system. The written goals and objectives served as the starting point for interviews with key personnel.

Step three consisted of semi-structured interviews with members of the radiology staff, radiologists and other users of radiologic information, both clinical and managerial. All interviews were conducted in a similar manner and included a description of the nature of the study; questions regarding informational needs of and demands by the individuals; questions regarding perceptions of how a computerized system could help individuals retrieve information and perform their work; and probing questions regarding specific informational needs.

In the fourth step, a structured, detailed description of the information needs in the Radiology Department was compiled. This preliminary analysis was then reviewed with key personnel and a final analysis was developed. This analytic framework served as the basis for developing a series of tests for measuring the accessibility and availability of information in

the Radiology Department.

Using the final analytic framework as a guide, the fifth step entailed selecting 20 examples of information needs to use as test items to measure the accessibility and availability of information. Examples were chosen on the basis of three criteria: (1) the potential for the computerized system to influence information accessibility or availability; (2) the degree to which the example was representative of the present or anticipated information needs of the department; and (3) the degree to which the accessibility and/or availability of the information was measurable, either quantitatively or qualitatively.

Although the results of this study must await the post-implementation phase for full interpretation, limited observations can be made. Despite perceived inefficiencies, the methods which had been developed or had evolved for information handling appeared to meet most of the needs for day-to-day operations. Information which could be used for research and teaching, while theoretically available, was not utilized because of the logistical problems in accessing and organizing data from charts and jackets.

3. Unbilled Examinations

Services provided by the Harborview Radiology Department are billed to patients through the University of Washington Hospitals billing system. The source documents from which bills

were calculated under the former information processing system were prepared manually by department personnel. Given the large volume of business conducted by the department, some amount of error in the billing system was bound to result. One aim of computerizing the department's information system was to reduce the likelihood of that error by facilitating the monitoring of the service information that enters the billing system. The objective of this portion of the study is to compare the accuracy of billing information compiled under the manual and automated systems.

Essential to this assessment is the ability to ascertain that an exam has, in fact, been conducted; and that a discrepancy between exam and billing records is not, in fact, an oversight by the evaluator. For these reasons, three independent sources of information on exams conducted were compared: the two-week sample chosen for the timeliness assessment, a written log of exams conducted, and the billing record for the same two weeks.

By comparing these three relatively independent records, the evaluators could make note of those cases in which there was no billing record for exams noted in both of the other two sources. Such cases were counted as unbilled exams. Cases in which only the log or the timeliness study indicated an exam, with no corresponding billing record, were not counted as unbilled. Consequently, the count of unbilled exams obtained

may be slightly underestimated.

Results of the study suggest that there were indeed cases in which exams conducted by the department were not billed. For the two-week period sampled, an amount equal to approximately three percent of total billings was apparently not billed. The type and distribution of unbilled exams approximated the general distribution in the department. The information gathered will serve as a basis for comparison with billing accuracy under the computerized system.

4. Attitudes toward the Radiology Department

The attitudes of those who work in and with a radiology department serve as an important barometer of how well the department is discharging its responsibilities. The objective of this segment of the study is to assess changes in the attitudes and levels of satisfaction regarding the department that may relate directly to the implementation of the computerized information system.

The principal aim in designing this part of the study was to collect, in the least invasive manner, the most useful information on the attitudes of three significant groups of personnel: radiologists, non-physician Radiology Department staff and physicians who order exams from the department. The information desired can be grouped into four categories: (1) general information on the respondent such as nature of position, length of employment at the hospital and amount of

contact with the Radiology Department; (2) use of and familiarity with the current information system; (3) attitudes toward and satisfaction with the way in which the Radiology Department functions; and (4) experience with and attitudes toward computerized information systems.

Given the desire to reach the maximum number of potential respondents within the time constraints brought on by the pending installation of the computer, it was decided that a mailed questionnaire was preferable to telephone interviews as a means of collecting the needed information. Three questionnaires were designed to capture the information, one for each group of respondents.

Since changes in attitudes may be brought about by changes in the practice of radiology as much as by the introduction of a new information system, a comparison site, University Hospital (Seattle), was used for this part of the study. Consequently, six versions of the questionnaire (three for each site) were mailed with an accompanying cover letter. The letters, cosigned by the Chief Radiologist and the Medical Director for the respective hospital, explained the purpose of the study and urged cooperation by the respondents. Recipients of the letter were assured that their responses would be treated confidentially.

The initial rate of response to the mailing, nearly 30 percent within the first five days, was somewhat encouraging.

Unfortunately, the rate dropped thereafter, necessitating a rather intensive telephone follow-up effort (pre-assigned control numbers allowed for follow-up, but were not used to link responses to individuals). The final response rate was approximately 57 percent. If one excludes the associate attending staff, who rarely (if ever) use the hospitals in question (and who consequently had an extremely low response rate), the overall rate improves to 60 percent. The rates were highest for radiologists and department staff, probably because of reinforcement of the importance of the study from administrators and a greater general interest in its outcome. Among other physicians, responses were highest for the active attending staff, the only group to receive telephone reminders. This suggests that telephone contact can serve to improve response rates in studies such as this. A mailed questionnaire, while easier to administer than interviews, is also, unfortunately, easy for subjects to ignore.

The responses to the attitude survey, while not overwhelming, did yield some interesting results. For example, most physicians (non-radiologists) responding indicated a tendency to rely on their own judgment of a radiology exam before relying on either a formal or informal report from the radiologist. For results of prior exams, respondents noted a reliance on both the films and the reports. It has been observed that physicians treating inpatients at Harborview

frequently examine radiographs and consult with radiologists shortly after exam results are available (and before the written report is available); while outpatient exam results, for which there is less urgency, are more often conveyed through the written report. This was not verified by the study.

Most physicians expressed no preference for either a more detailed or more summary form of the written radiology report. As to the speed of access to the written report, those physicians with an opinion tended to express dissatisfaction. Consultation with radiologists, the verbal counterpart to the written report, was reportedly initiated for 1 to 25 percent of the exams requested by physicians. The most frequent reason given for such consultation was to discuss radiographic film interpretation.

Most of the radiologists and other physicians appeared to accept the application of computerized information systems to radiology departments, and a number favored the idea. Of those expressing an opinion, most said that they would implement such a system if they were in charge of the radiology department. While most radiologists indicated that they had not worked with a computerized information system, most of the other physicians indicated that they had.

5. Departmental Costs

A system that is intended to improve the efficiency of information processing is also expected to contribute to savings

in processing costs. Consequently, this segment of the evaluation was designed to ascertain any changes in costs to the department following installation of the computer system. This study is not intended to be a rigorous cost-benefit analysis; it is rather an observation of changes in specific costs to the department over a period of time.

The approach taken in this study was straightforward. Records of Radiology Department expenditures for the fiscal year preceding the installation of the computer system were examined. Included in the analysis were direct personnel costs (excluding radiologists' fees, which are billed through a separate system), and costs for services and supplies. Acquisition, installation and servicing costs of the computer system will be examined as separate items (to the extent separable) in the second phase of the study. Expenditures were summarized by classification of expense according to the Harborview accounting system. To attempt a greater level of detail would have required a review of all invoices from the many vendors serving the department. This detailed an analysis was never contemplated by the evaluation team. The units of analysis, therefore, are expressed by such classifications as "medical supplies", "film", "photocopying" and the like.

In order to account for increases or decreases in workload between the pre- and post-implementation observations, all figures were converted to a cost-per-exam basis, using the total

number of exams for the fiscal year in question. Changes in the mix of exams over time, if any, will be more difficult to assess and will have to be estimated from departmental records and from data obtained from other parts of the study.

Inflation, of course, will have a significant impact on departmental costs. While an attempt will be made to secure inflation estimates for as many cost categories as possible, the results for the second observation period will probably reflect an average rate.

Having calculated costs per exam for the major expense categories, the next step will be to repeat the process for the post-implementation observation.

ISSUES

The study design presented here is only one of many options available for the evaluation of a computer system's impact on a radiology department. Regardless of the design selected, however, a number of issues bear considering prior to implementing such a study. Several are presented below.

Know Your Objectives

Not only must the evaluation's objectives be clearly stated, but so must the objectives for the computerized information system. The two are very closely linked, for any evaluation must determine the extent to which the purchaser's objectives have been met.

Minimize Your Impact

It is difficult to conduct an evaluation of a system without having some impact on that system. The object is to keep one's impact to a minimum. In attempting to minimize impact, one should learn as much as possible about the system being evaluated, then design the evaluation to fit as smoothly as possible into the system's routine. One should avoid introducing instruments or methods of observation that will either be disruptive or will tend to influence the type of data being gathered.

Seek Cooperation from Those Who Have Charge over the System

Changing a system or introducing a new one can be a very trying experience for all involved. To introduce additional change, in the form of an evaluation, may very well be met with resistance. One must therefore engender cooperation wherever possible by explaining the purpose,objectives and expected benefits of the study. Where this is not possible--for example, where subjects must not know that they are being studied--every attempt should be made to avoid adding to any existing inconvenience.

One way of engendering cooperation while minimizing interference at the study site is to have those in charge of the system introduce the study. This study team is fortunate in having worked with very cooperative administrative and supervisory personnel at Harborview from the earliest stages of

the study. Their cooperation has made a big difference in the ease with which the evaluation has proceeded.

Expect the Unexpected

In any dynamic situation, such as one in which a new information system is being implemented, there are bound to be unexpected events or factors that can confound the results of an evaluation. One cannot anticipate all such variables; and even if that were possible, one cannot always avoid their consequences. Because the unexpected can happen, it is advisable to keep the evaluation plans as flexible as possible. One must also be watchful for subtle occurrences that can effect a study's outcome, such as changes in other parts of the institution that have an ultimate, albeit undetected, influence on the department being studied. The best one can do in most cases is to make note of any confounding variables and to take them into consideration when drawing conclusions from the study.

CONCLUSION

Evaluation of a radiology computer system can take a number of forms. An example of one such form, as administered in the radiology department of a major teaching hospital, has been presented here. It is hoped that some of the lessons conveyed and examples presented will aid others who are contemplating similar studies.

THE FORMATION OF A RADIOLOGY COMPUTER CONSORTIUM

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Background

The concept of applying computer technology to clinical activities, particularly those in the hospital setting, has been recognized for over twenty years. Radiology has been in the foreground of the many clinical services where automation has been shown to provide advantages over manual operations. This is due in part to the large volume of repetitive procedures inherent in radiology practice and the acceptance by radiologists of the utility of expensive, complex equipment in providing diagnostic and therapeutic services. By the mid 60's it was apparent that the constantly increasing radiology workload could not be accommodated merely by increasing the size of the staff, expanding the physical plant and purchasing more x-ray equipment. Reaction to the increasing costs of medical care was mounting and the availability of trained personnel was decreasing.

At the same time, computer technology was changing at a rapid rate and the number and variety of applications in business, industry and government were increasing dramatically. New computer hardware was offered that permitted remote access, the processing of multiple programs, and a variety of output options, all of which opened new market areas. The number of computer oriented investigators in clinical environments increased, Public Health Service support of computers in medicine expanded, and the discipline of biomedical engineering became a reality at many academic institutions.

Among the early investigations of computers in radiology were

several projects sponsored by the Bureau of Radiological Health. In order to reduce the delay between the interpretation of a diagnostic x-ray examination by a radiologist and the availability of the report to the requesting physician, an automated reporting system was developed at the Johns Hopkins Medical Institutions in 1968. Efforts to improve the scheduling of patient examinations and to locate x-ray film jackets resulted in a radiology information system at the Massachusetts General Hospital in 1971. The reporting system was adapted by several firms and became commercially available in 1975, and the scheduling and tracking system was modified and installed at the Hospital of the University of Pennsylvania in 1977. Efforts to market the system commercially were not successful.

During this period changes in computer technology accelerated, computed tomography became a common diagnostic modality and the costs of automated data processing, storage and retrieval declined dramatically. Among the developments, the availability of minicomputers and distributed systems made possible a design for radiology information systems which was technically feasible and economically viable. The result was that it was no longer necessary for the Radiology Department to be dependent upon a distant central computer for information and data processing services. It was clear that a dedicated system under the control of the Radiology Department could serve radiology's needs, and through linkage with the central computer, could obtain existing information and transfer data required by the central system.

Despite the favorable technical climate, successful installations of

radiology information systems have been relatively scarce. The reasons for this are not clear, but the contributing factors include: previous failures in the market place, more profitable alternatives available to potential vendors, the uniqueness of different radiology practices, and the dispersion of decision making authority in medical care facilities. After a great deal of consideration, it was felt that most of the obstacles could be overcome by organizing the potential users, namely the Radiology Departments, into a cohesive group. The organization would specify the common requirements of the discipline for automated systems, share in the development of the products, establish a sizable market and provide the leadership necessary to gain recognition of radiology requirements by hospital administrators, governmental authorities and private industry.

Exploratory Meeting

In order to explore the idea of joining experienced users with vendors to create a new management system, approximately 150 invitations were sent, in September 1980, to hospitals and potential vendors which had previously expressed interest in the system in use at the Hospital of the University of Pennsylvania (HUP). Much to our surprise, eighty institutions and vendors sent representatives to discuss the possibility of forming a Consortium. Different approaches toward the establishment of a Consortium-vendor relationship to produce this new management system were explored.

Many participants contributed ideas about the advantages which both

Consortium members and vendors would derive from such a relationship. The concept of a group of experienced and knowledgeable users guiding a vendor in order to produce the best possible management system was most attractive. To be able to build on the background of successful systems already in operation in academic centers would certainly help insure success for the vendor. Yet having a commercial vendor retain at least some of the rights and be responsible for the marketing and maintenance in a clearly for-profit arrangement would help guarantee the proliferation of the system. The pooled talent and experience of Consortium members and vendor would certainly minimize development time. The Consortium members would be guaranteed the lowest possible price as well as significant input into future updates and the vendor would be provided promotion and endorsement by the group as well as ongoing advice. Through consultation and user group meetings, Consortium members would also be able to take advantage of the experience of those members already having installed systems.

Consortium Organization

Because of the considerable interest expressed at this exploratory meeting, the various options for organizing the Consortium were further analyzed. It became clear that the creation of a separate non-profit corporation would be costly and time-consuming and would drain any financial resources that a Consortium in its infancy might be able to gather. After preliminary discussions with representatives from The Pennsylvania Hospital Services Association (PHSA) of the Hospital Association of Pennsylvania (HAP), the affiliation with an already

established non-profit service organization seemed to be the most advantageous arrangement. Therefore, the Radiology Information System Consortium, whose acronym RISC was adopted with the full knowledge of the implications, was established within PHSA. Since, under the by-laws of the PHSA, only non-profit hospitals or other health care facilities located in the United States may join, invitations were limited to interested non-profit hospitals.

Management Committee

Initially, twelve hospitals joined the Consortium (Table 1). The Consortium was officially formed in February 1981, and the first meeting of the Management Committee, which consists of the twelve original members, was held in March 1981. By June 1981, a Task Force made up of several members of the Management Committee completed a Request for Proposal (RFP), which was sent to interested vendors in August 1981. The Management Committee serves as the board of directors for the Consortium. The various task forces carry out specific objectives and report to the full Management Committee for approval.

System Design

A series of generalized concepts was incorporated into this RFP; these concepts go far beyond functional requirements and may well prove to be the most important contribution of the entire Consortium effort. The following list enumerates some of these concepts:

TABLE 1

MANAGEMENT COMMITTEE

Brigham and Women's Hospital, Boston, Massachusetts

Duke University Medical Center, Durham, North Carolina

Henry Ford Hospital, Detroit, Michigan

Holy Family Hospital, Spokane, Washington

Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania

Long Island Jewish-Hillside Medical Center, New Hyde Park, New York

Mallinckrodt Institute of Radiology, St. Louis, Missouri

Montefiore Hospital and Medical Center, New York, New York

University of Massachusetts Medical Center, Worcester, Massachusetts

University of Texas Health Science Center, Dallas, Texas

University of Utah Medical Center, Salt Lake City, Utah

Yale-New Haven Hospital, New Haven, Connecticut

Technical assistance provided by the Bureau of Radiological Health

1. Detailed documentation specifications
2. A highly table-driven and user-modifiable system
3. Fast system response times
4. Priority-driven functions
5. Functional-level security and passwords
6. Transaction logging for accountability

7. High-level language and database
8. Generalized report generator
9. CRT formatter
10. User-friendly entry prompts
11. Message broadcasting
12. Communication interfaces
13. Check point re-entry
14. High reliability
15. Prompt maintenance

Functional Requirements

The major part of the RFP consisted of the detailed functional requirements for this new management system. Each of the members of the Management Committee brought different perspectives to the discussion and made major contributions to these documents. Perhaps the most amazing discovery was that this diverse group of representatives from major institutions could so completely agree on a set of requirements for a management system. The following list summarizes the major modules included in the RFP:

1. Registration
2. Scheduling
3. Fileroom Management
4. Results Reporting
5. Management Reporting
6. Communication Interface

7. Patient Tracking
8. Accounting
9. Word Processing
10. Teaching File
11. Equipment Maintenance
12. Contrast Reaction Reporting
13. Utilities

Bidders' Conference

All vendors intending to respond were invited to a conference in September 1981, so that they could collectively receive clarifications concerning the RFP to simplify the response process. Seventeen vendors attended this meeting. They not only received answers to their questions but also were made aware of the extent of commercial interest in the Consortium and the significant degree of competition that they would encounter.

Vendor Selection

During the meeting of the Radiological Society of North America in November 1981, the Management Committee heard the final report of the Vendor Selection Task Force. Based on a carefully established set of selection criteria, the report indicated the best three vendor proposals. Operating under the auspices of the Vendor Selection Task Force, a team was appointed to begin negotiations with these three

vendors. These discussions began shortly thereafter and continued for several months. Finally, a contract was signed with Digital Equipment Corporation (DEC) for both software and hardware in April 1982. A public announcement of the contract between the Consortium and DEC was made at this conference.

Development and Test Sites

Several of the Consortium members have been identified as development sites. These institutions will be responsible for assisting the vendor to complete the detailed system specifications, CRT formats, and report formats. These sites will perform the earliest software testing. Along with representatives from other Consortium members, representatives from these development sites will comprise the Development Task Force which will represent a unified position in the on-going interaction with the vendor.

The same or different sites will be selected to serve as test sites. These institutions will perform advanced software testing and program debugging as well as review of documentation and analysis of system performance. The difficulties of user customization will be explored during this phase.

Ongoing Activities

We expect to have a substantial number of systems installed at Consortium hospitals within the year. As soon as a sufficient number of

systems are up and running, a Users' group will be established to share ideas, problems, and solutions. This group will perhaps consist not only of Consortium members but also of government hospitals and for-profit hospitals which have purchased the system outside of the Consortium. It is also anticipated that hospitals in foreign countries will be able to purchase the system, although they are not eligible for membership in the Consortium. Of course, the Consortium, through its Management Committee, will administer and guide this user's group.

Future Projects

It is clearly the intent of the Consortium to move on to other projects once the management system is established. Although the Management Committee has not decided which future projects would be of greatest interest, the following ideas have been considered: Picture archival and communication system, voice input reporting, standardized x-ray generator interface, digital image receptors, and computer assisted instruction. There is little doubt that in any of these areas potential vendors could use the encouragement of such a group of sophisticated users and would also benefit from their guidance. The Consortium will hopefully act as a catalyst in the development of systems which are currently not viewed as ventures with low enough risk and high enough profit for most vendors. The Consortium should be able to establish a new channel of communication between users and vendors. The Consortium should also serve as consumer advocate, should assist in setting standards, and serve as a clearing house for ideas and applications.

Summary

The Radiology Information System Consortium, representing some of the most prestigous institutions in the country, has now achieved several important milestones on its way to developing the latest, most sophisticated information management system for radiology. The Consortium has successfully created the detailed functional requirements of the system, has contracted with a vendor for both hardware and software, and has determined the development sites. RISC's birth is now complete. It is anticipated that multiple systems will be installed within the year.

HOW TO PICK A PARTNER WITH WHOM TO DEVELOP A RADIOLOGY INFORMATION SYSTEM (RIS)

THE BIRTH OF "RISC'S" FIRST PROJECT

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Introduction

"RISC" stands for Radiology Information System Consortium. RISC is made up of a group of hospitals which have perceived a need for a Radiology Information System (RIS). Among representatives of the member hospitals there is considerable experience in the development and use of Radiology Information Systems. Early, RISC members reached the consensus that the market had not yet fully addressed Radiology's needs and that a major new development effort was warranted. In support, the Hospital of the University of Pennsylvania (HUP) offered its operating RIS as a model for the consortium. The HUP system is the culmination of many years of developmental efforts by several institutions and vendors who followed the original developmental efforts of Massachusetts General Hospital (MGH). From its inception, this line of development has been nurtured in a variety of ways by the Bureau of Radiological Health (BRH). BRH has continued its support through the years of recent development at HUP and the formative months of RISC to the present day. (1)

The HUP system has excited a great deal of interest in the radiologic community because it works, it is comprehensive, and it appears to be cost effective. However, certain technical limits have been reached, and a number of desirable enhancements are not feasible unless they are incorporated in a new generation of the system.

The existence of a good prototype, widespread need and interest, and the timeliness of a major system revision, inspired a meeting of repre-

sentatives from approximately eighty institutions interested in the possibility of participation in a joint development effort. HUP offered to donate access to its system down to full specification of its functional qualities. Specific program code was excluded.

From the congregation of medical institutions interested in Radiology Information Systems, a not-for-profit subset of the participants formally united as a consortium incorporating under an administrative service subsidiary of the Hospital Association of Pennsylvania (HAP).

The consortium (RISC) revised, refined and upgraded the functional specifications for the RIS offered by HUP. Through this process a multiinstitutional agreement on specifications, including modularity, flexibility and range of system environment to be accommodated was reached. This agreement had substantial marketing implications because it could be expected to reduce the risk taken by a developer who wished to incorporate innovations necessary to produce a system that could be labelled as "state-of-the-art". It was one intent of the consortium, by reducing the vendor's risk of innovating, to markedly narrow the usual gap between marketable systems and state-of-the-art systems typically found in individual research institutions.

At the time RISC was formed, however, it was not clear that an outside vendor was the developer of choice. The consortium carefully considered a full range of options from a completely internal development project with subsequent marketing by RISC, to a fully external project of analysis, development, and marketing by an independent party or parties.

Because RISC is an advocate of meeting consumer needs, the consortium

wished to retain control of design and to remain in a position to influence marketing policies. The most obvious way to accomplish these objectives would have been for RISC to do the entire job itself. However, as analysis of the project proceeded, it became apparent that neither developmental funding nor the complete spectrum of necessary expertise would be available from within the consortium alone. Not having the resources to unilaterally produce the system, RISC had to seek a partner with whom a mutually satisfactory relationship could be negotiated.

Search Process

Through its membership, RISC clearly had specific and comprehensive experience, knowledge and expertise in the development and operation of radiology information systems. RISC also had access to a sophisticated RIS which had been extensively tested in a demanding working environment. What RISC needed in a partner was an organization that had preeminent experience, expertise, and capability in the design, manufacture and marketing of medically oriented computer hardware and software systems. That organization also had to be willing to grant sufficient participation and control to RISC so that the consortium could approve the system for the market at large.

Since RISC wished to establish a unique working relationship for which no precedent was known, it needed to devise a method to identify a set of potential partners. Because the complimentary expertise sought, clearly appeared to be typical of that found among vendors, it was decided that RISC would take a standard purchaser's approach to the target group. Consequently, a formal Request for Proposals (RFP) was developed and distributed. Interested parties were also invited to

attend a demonstration and question session at HUP to examine the model system and to receive clarification of any questionable matters before submitting final proposals. Nearly one third of approximately twenty attendees submitted their formal documents.

Choice Process

RISC's Vendor Selection Task Force, with the aid of a formal criterion set, reviewed all submitted proposals in detail. The review process not only reduced the number of vendors under consideration to half, but also allowed the task force to restudy RISC's position with respect to the evolving set of potential partnership profiles. The task force reviewed the functional specifications and developed a position on gaps and equivocal items. Documentation requirements were similarly refined. Most important, however, was the opportunity for the task force to sophisticate its understanding of partnership options and to detail a set of alternative partnership relationships.

Letters notifying the disqualified vendors of the task force's decision were then distributed. The remaining contenders each received a digest of the task force's analysis of their proposals and a series of individualized questions designed to develop the transition from the usual buyer/vendor relationship to the desired partnership relationship.

From the vendor's replies to the foregoing letters, the task force determined that each vendor had sufficient interest and qualifications to be considered a potential partner. Each of the vendors held some unique value, each approached the prospective project with a different point of view. An additional phase of exploration was clearly necessary. Consequently, each vendor was invited to convene with the RISC Vendor Selection

Task Force for further substantive exchange. Because the RISC/Vendor relationship was in transition, and the meeting was expected to acquire the character of negotiation, each vendor was asked to include at least one team member with the authority to make fundamental contractual decisions. Each vendor complied and the meetings were highly effective.

As expected, each of the meetings developed its own identity depending upon the strengths and weaknesses of the participating vendors. Three basic issues were layed upon the table:

1) did the proposed system and its technical support constitute a reliable means to solve the problems posed by RISC's functional specifications,

2) could agreement be reached on a common goal and on a balance of power that would allow a true partnership to be established, and

3) were the available resources, including financial, sufficient, as well as adequately committed, to assure completion of a Radiology Information System that would fully satisfy the explicit common goals under which the partnership would be formed?

At the termination of these meetings the possibility of adequately and simply meeting all three issues with more than one vendor remained. However, each vendor left with several questions to be resolved. The quickly forthcoming replies to these questions clearly identified one vendor as the leading contender for partnership with RISC. Nevertheless, it was felt that negotiations would be sufficiently complex so as to leave some doubt that all issues could be resolved before the final agreement was ready for signature.

At the time of this writing, the announcement of that final agreement is imminent, and a high quality, versatile, state-of-the-art Radiology Information System is expected to be the product of the resulting partnership.

Conclusion

It has been the purpose of this paper to describe the process by which the partners in an innovative venture came to meet and join. This is not a business chronicle. Much of the specific discussion concerned proprietary information not appropriate to this publication. To name the specific vendors would add nothing to an understanding of the process described. The process itself is an experiment in finding ways by which the high technology for information management can be more effectively, and thereby more cheaply, placed in the hands of the user. This project has been focused on Radiology, but the experience is transferable. It, therefore, is hoped that this and future projects will help to reduce the gap historically found between market offerings and the state-of-the-art systems found in research institutions. And it is hoped that in the long run this venture will contribute to better, more cost effective medical information technology being offered in the competitive, free enterprise market.

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AN OPERATIONAL RADIOLOGIC INFORMATION MANAGEMENT SYSTEM

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Abstract

Experience with a minicomputer based radiologic information management system which is operational at a medium size hospital in Western New York is described. This system was designed to be modular in installation and implementation. This installation features a dedicated radiology department minicomputer which is interfaced to the hospital's administrative computer. The multitude of software functions which comprise a "complete" radiologic system are enumerated and their status in this system is addressed. The role of interfacing inexpensive stand-alone word processors and microcomputers is addressed. The presentation illustrates a variety of hardware and software options depending on the users' priorities of function.

Introduction

Eight years ago, while practicing at a large county hospital, we were involved in the development of a radiologic reporting system. Exposure to the multitude of computer applications for radiologic practice has been constant since that time despite practice relocation and severance from the initial project for several years. Increasing clerical workloads and a desire to change to a more efficient film filing system recently precipitated a long-overdue evaluation of our current radiology department's automation needs. After defining the needs of the hospital and the radiological group, alternative solutions were weighed, cost analyses were obtained, and a decision to implement a radiology information management system was reached. The hardware and

software was to be modular and implemented in stages. A close working relationship with a commercial medical software house was established and the initial modules of our automation project were installed in November 1981.

Our Lady of Victory Hospital is a 275 bed Catholic hospital located in Lackawanna, New York, a suburb of Buffalo. The radiologic department consists of 6 diagnostic x-ray rooms including computed tomography, a wet lab and an imaging room for nuclear medicine and ultrasound. The case load is approximately 60,000 examinations per year.

Hardware

Our present system centers around an IBM Series/1 minicomputer whose functions are dedicated to the radiology department. It has on-line bisynchronous communication with the Hospital's administrative computer, an IBM System 3. Both systems run twenty-four hours a day, seven days a week. The department's present Series/1 configuration consists of:

- 4055F processor with 128K-byte memory
- 64 Megabyte fixed disk
- 0.5 Megabyte removable diskette
- 4978 CRT/Keyboards (3)
- bisynchronous communication line
- 120 cps Texas Instrument matrix printers (2)

We anticipate adding two more 4978 CRT/Keyboards and a character printer in the immediate future for reporting and transcription purposes.

Unlike the traditional larger IBM computers, the Series/1 is offered as unbundled modular components. The 4955 Processor is quite powerful and can expand to accommodate 512K-bytes of memory. It can handle up to 256 I/O devices in any combination of disc drives, CRT's, printers, or other peripheral devices. It is very versatile and applicable to virtually any computing task including sensor-based I/O applications, traditional data processing, scientific computing, and distributed data processing. It is reliable and has had no significant down-time despite continuous usage, 24 hours a day, seven days a week. Maintenance service has been excellent. Communications include asynchronous and/or bisynchronous interfaces. Multiple attachment features allow a multitude of both IBM and non-IBM peripherals to be linked to the CPU. The Series/1 price is competitive with other mini-computers.

System Software

The operating system utilized is the EDX (Event Driven Executive) system. Another software product, EDX Multiple Terminal Manager (MTM) is also incorporated into the departmented system.

The EDX Supervisor allows multiple copies of the same program or multiple independent programs to run concurrently. Each independent application can support internal multitasking with preemptive task switching. The multiple terminal support allows dynamic assignment of terminals as required by the application. Compiling or link editing can be done concurrently while executing

other application programs. The CRT/Keyboards feature 32 special function keys with the capability of the entire keyboard being redefinable.

Application Software

Most of the application programs utilize menu driven formatted static screens. Hierarchical security checks govern access to the terminals, to user software partitions, to specific application programs and to data files. Extensive field edit checks and error prompts are incorporated in the programs. Data integrity checks, error recovery programs and auxiliary problem solving subroutines facilitate file and data integrity.

Our requirements definition eliminated the need for many commercially available applications. Size and cost constraints relegated the following applications as non-essential in our institution:

- examination request generation
- patient, personnel, exam and room scheduling
- patient and jacket tracking
- computer-aided diagnoses
- quality control and assurance
- technique and patient exposure records

The most pressing needs were for quicker, more accurate patient registration, more efficient film file control, alleviation of the ever increasing burden of manual statistics, and more accurate capture of professional and technical charges. The first phase of the installation addressed all four of these areas.

Registration

All patients coming to the hospital for any service must first be registered on the Hospital's System/3 at the emergency room, admissions or outpatient registration sites. The department system is interfaced to the Hospital's System/3 and can interrogate the hospital's registration files. The department receptionist registers a patient by keying in the patient's last name, first name, and birthdate. This generates a code which searches the radiology department's master directory for an equivalent code. The code and the search are transparent to the user and extremely quick. If no match is found, the patient is not on file. The Hospital's files are then searched and the recently entered patient demographic data and subscriber data are displayed. If the patient is on file, his data is retrieved and displayed. The receptionist validates the data and enters the service rendered. For those new patients, a unique 9 digit number is generated by the computer for use as the permanent film file and patient identification number. Labels are printed out for use on the patient's flash card and envelope.

The communication with the Hospital's system, which is not an absolute requirement, has greatly speeded registration not only by eliminating repetitive input of most patient and demographic data but also by eliminating time consuming manual retrieval of the patient's film number from our 3x5 card file.

Film File Control

Film file control was enhanced by conversion to a permanent

department identification number and color coded terminal digit filing. Yet we still use alphabetizing for current patient file.

Statistics

The system is extremely strong in statistical reporting. Monthly and yearly departmental statistics were previously compiled manually by the chief technician. He has been freed from this paperwork by an extensive set of statistical programs. A variety of print formats facilitate interpretation of the usual management reports.

Billing

Lost and late charges have been virtually eliminated by virtue of the communication link between the Hospital and department systems. Professional and technical components are recorded and preserved throughout the system. Billing for all professional components and for some technical components for some contracts is done by an integral service bureau in batch mode. The data is transferred by diskette or by bisynchronous phone line to an identical Series/1 remote to the hospital. All billing modules can be run on the department computer but currently the radiologists prefer the actual billing to be done remotely. The billing modules print third party forms as well as private statements. The modules include cycle billing with user selected dunning messages at user designated periods of time.

Financial statistics are also extensive and print formats are user selective. Reconciliation of accounts receivable with the hospital for technical components billed by the radiologist are

currently done by manual comparison of the hospital's and radiologist's ageing listings. Computerized matching and reconciliation is an anticipated enhancement.

Future Applications

Reporting has the next priority on our time frame and is currently being developed. We plan to install it in two phases with coded, "canned" texts being installed first. This is about ready for implementation. Incorporation of dictation entails free text entry and word processing capabilities which are being developed in MTM format. We entertained linking microcomputers with word processors as an alternative to developing a full reporting system on the Series/1. We were able to link microcomputer screens and printers to the Series/1 but their use appeared limited to the word processing aspect of reporting. The reporting modules encompass much more than word processing in our design and so we do not anticipate microcomputer linkages at this time, at least not for our reporting module.

We currently have a teaching file module modeled after the Radiology File of the American College. It is not in MTM format and its conversion has low priority because it is currently usable in non-MTM form.

Summary

We have installed a dedicated minicomputer in the radiology department which is linked to the Hospital's administrative computer. We have implemented our highest priority functions and have seen beneficial results. We look forward to expanding the

uses of the minicomputer within the department and are confident of attaining significant benefits with minimal increased costs.

EXPERIENCE WITH A DEDICATED RADIOLOGY INFORMATION MANAGEMENT SYSTEM

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Harborview Medical Center (HMC) is a 326 bed County owned acute care facility in Seattle, Washington. It is managed under contract by the University of Washington as a teaching hospital for undergraduates and graduates in Medicine, Nursing, Social Work, and other health related disciplines. It admits nearly eight hundred patients a month, the majority of these through Seattle area's busiest Emergency Department. The Outpatient Clinics average 9477 patient visits per month; the Emergency Department averages 2677 visits per month. Eighty-nine resident physicians, augmented by varying numbers of clinical fellows provide health care services under the supervision of several hundred different Medical School faculty.

Because these programs are integrated into a comprehensive City-wide clinical training system, rotation of residents takes place frequently and new names and faces abound in the ranks of the care-givers who refer patients to the Radiology Department.

The Center, itself spread over approximately four city blocks, is a mixture of old and new. The Center Wing was completed in 1931, and houses the bulk of the Radiology Department. A Clinic Wing was added in 1953, while a second modern North Wing was completed only last year, to permit expansion of Inpatient and Emergency services. Further expansion of the plant is planned at present.

The Hospital Radiology Department has experienced growth during the past decade. To carry out its mission, Radiology had

to develop a major satellite in the new North Wing, as well as two smaller satellites in the older Clinic Wing. Demands for service have increased nearly twofold during this time. The Department presently accomplishes 70,000 procedures yearly, of which nearly 20% are bedside examinations, and 40% are conducted in the Emergency Department, most of them outside regular working hours.

The Main Department, located on the ground level of the Hospital houses two fluoroscopic/radiographic laboratories, a conventional precision tomography laboratory, a chest laboratory, a general radiographic laboratory, an ultrasound laboratory, and a computed tomography (CT) laboratory. Additionally, several film demonstration/reporting rooms adjoin the Main Department File Room. Film storage is on the level below, connected by a small dumbwaiter. Faculty offices and transcription are on the floor above.

The major satellite, in the Trauma Center, includes a small office, two general radiographic rooms and an angiography/special procedures room. This satellite is in continuous operation around the clock. Small clinic satellites serve Orthopedic and Urology outpatients at some distance from the Main Department.

A staff of 29 technical and 17 clerical workers support this operation. Five Radiology Residents are on site (at least one at all times), and six Radiologists, and a part-time Physicist complete the personnel compliment. Some Radiologists based at other hospitals attend at times, as well.

There has been ample evidence that the Department's performance was falling short of its aims in recent years. Anecdotal impressions of delays in service, increases in delinquent film loans, and lost billings were confirmed in a formal study by a team from our School of Public Health and Community Medicine (1).

We were not without resources to change our situation. Among our assets were a sympathetic Hospital Administration, a nest egg of dollars for equipment, and the support of the University Hospital Management Information Services (HMIS).

HMIS is organized at the University to Washington to provide computing and financial services for University Hospital and Harborview Medical Center. On the HMC Radiology Computer Project, HMIS provided professional assistance with computer system specifications, acquisition documents, proposal evaluation/vendor selection, contracts, site preparation/equipment installation, project management, mainframe computer interfacing, and software implementation/acceptance testing. On a continuing basis, HMIS will be providing technical assistance with system enhancements and other activities necessary to effective operation of the Radiology Computer System in the distributed processing environment of University of Washington Hospitals Data Communications Network.

The decision to acquire an automated system for data processing at HMC was part of an evolving effort to improve departmental efficiency. We had traced the flow of requisition forms, studied

lost billings, noted a large (and increasing) file room work load, and experienced an increasing time delay in obtaining finalized reports. New imaging rooms and reporting stations were being created, and services were being added such as computed tomography. The simple expedient of expanding the work force to keep up with the increasing work loads seemed a suboptimal use of our resources.

Consequently, we looked carefully at the possible improvements we might expect from automating as much of the Department as possible.

There were six general objectives sought through use of an automated system. These were: 1) to improve patient care; 2) to increase file room efficiency and productivity, including tracking films and associated date; 3) to speed rediological reporting and documentation; 4) to improve Departmental management and productivity through better quality control, more efficient utilization of resources, and better traffic flow; 5) to acquire data to enable the correlation of clinical information with radiological findings for the purposes of teaching, research, and the improvement of clinical practice; and 6) to reduce costs and improve financial accounting procedures.

Each of these six categories was expanded to the level of detail necessary for the purchase of a complex radiological information system. Functional specifications were drafted for scheduling, master folder tracking, reporting, transcription, and statistics. A highly detailed description was constructed, giving

for each item the purpose, the required input, a synopsis of the data processing required, and the desired output. This document formed the basis of a Request for Proposal (RFP) which was sent to all of the then existent vendors. With the concurrence of the HMIS computer staff, the decision was made (as specified in the RFP) to purchase as close to a "turn key" system as was possible. Two vendors submitted viable proposals. We selected one vendor on the basis of cost and on the strength of the distributed data base processing system they proposed.

Although the system was to go through several growth phases prior to its final configuration (due to the release of hardware with increased capabilities, and to increased requirements on our part), it originally was considered to consist of three processors, eight CRT's (6 stationary, 2 portable), one dual floppy disk, two hard 20 MB disks, two 120 cps printers, seven bar code readers, and two card readers. The system was to communicate with the main hospital computers (dual Burroughs 6700's) through an asynchronous interface at 4800 BAUD. The components were to connect by a network of multiple twisted pair, and were to run at rates of 1200 - 19,200 BAUD. Response time was estimated to be less than 1/2 second at peak times.

The Burroughs was to continually update our files of newly registered patients who had some expectation of utilizing the radiological service. It also was to accept batched billing data from the Radiological Information System. The software was to be

purchased to operate the desired modules, and changes to the software were to be negotiated with the vendor.

Approximately six months after the contract was signed, our hardware needs were reconsidered. At the vendor's suggestion, we agreed to upgrade the system, at no cost to us, with more powerful CPU's and an 80 MB disk. We, subsequently, have increased the memory to 256K, upgraded to a total of eight intelligent CRT's, retaining four of the original type. At the same time, the BAUD rate was increased to 19,200 overall.

These changes came about as the result of Wang's new product relaeases, and threatened obsolescence of some of the originally specified equipment. Because of the hardware changes. we halted site preparation, developed new cable specifications and designed a new communications network. Site preparation resumed after some weeks of delay.

We encountered a variety of problems in acquiring and implementing the Radiology Computer System (RCS). They can be categorized as: a) certificate of need (CON): b) site preparation (electric utilities, heat/ventilation/air-conditioning, remodeling); c) distributed processing interface; d) personnel training; e) parallel testing; and f) departmental procedures adjustment. Some of these were perhaps unique to our situation. Most can be considered typical, but the actual size of the impact may vary with users. Some of these problems are discussed separately below:

Certificate of Need: A State process of need review was

required prior to releasing funds for the purchase of the System. This task required substantial time commitment from Radiology, Hospital Administration, and HMIS personnel. The review process added several months of calendar time to the front end of the acquisition cycle. The CON authorities were persuaded to concur in our statement of need, so the impact of this process proved to be minor.

Remodeling: Finding space to house equipment was difficult due to density of occupancy in the Radiology Department. Pre-existing departmental remodeling plans were modified to accommodate new computer equipment in existing work areas and areas already scheduled for general remodeling. Separate remodeling of former bathroom/storage areas was required to house central processor/disk equipment in a secure quality/ controlled environment. In this computer room, we used an air to water air-conditioner with optional access to direct outside air input or exhaust via a window in the room. Computer equipment was conveniently mounted on over-sized built-in adjustable shelving and work surfaces. Cabling was terminated in a series of easily serviced patch panels. Remote equipment was able to operate in our patient areas, in an ambient environment which was free from temperature/ humidity extremes.

Electrical Utilities: At HMC, electrical utilities were a real challenge, due primarily to the complexity and obsolescence of the existing supply and distribution system which had evolved over approximately fifty years of remodeling and

building additions, since the original construction in 1931. The task was further complicated by electrical noise and interference by-products of Radiology equipment resident in the vicinity. We had to run new dedicated computer system utilities, revise the Hospital grounding system, and install power regulation and electrical noise control equipment in order to meet computer system power quality requirements. In summary, the vendor's electrical specifications understated the real requirements. Communications cabling was also a substantial task and was installed concurrently with electrical utilities. Cost of combined utilities was substantial.

Distributed Processing Interface: Interface of the Radiology System to the HMIS Central System was a difficult task handled by highly skilled professional HMIS staff working directly with the vendor, but involving Radiology personnel occasionally, in specifying and testing the interface capabilities. The communications interface was TC-500 Burroughs protocol, modified slightly by HMIS. The product of this interface was ability to communicate and pass files, real-time or batch, between the systems. Currently, the systems interface for patient registration and billing purposes. Interfacing in general should be looked upon as possibly difficult, and strictly a task for highly skilled professionals.

Personnel: Radiology personnel required substantial commitment of personal time to prepare for the Radiology Computer System (RCS), as anticipated. Selected staff members were

assigned and trained to coordinate Radiology Computer System implementation activities, oversee computer equipment operation and revise departmental procedures. The heaviest time commitment was felt during implementation/testing. Some staff jobs have been enlarged; reclassification of others is expected. At Harborview, the radiology operation is a 24 hour/day, 7 day/week one. Some activities, such as patient registration, must be continuously available. During the installation phase, the RCS malfunctioned unpredictably. Specially trained staff were required on standby to respond to these system failures, and to maintain a problem log. While such failures are expected to become much less frequent in the future, the need for standby personnel and a problem log is a continuing one.

Parallel Testing: The greatest impact on the Department overall was parallel testing. In this process, we have continued to operate the Department the old way (pre-computer system) and concurrently tested the computer system during its software development and implementation testing stages. The testing process challenges departmental organization, increases net workload, tests patience and generally has its ups and downs.

Because the process was lengthy, it was very fatiguing. Comprehensive teamwork was essential. In this connection, the considerable talent and patience of John Mazur, representing the vendor should be acknowledged. In acquiring our system, we asked for a custom-modified, more sophisticated version of the vendor's

standard RIMS product. We asked for capabilities we wanted, but did not have. We also asked for capabilities which the vendor had not developed and had to invent. Substantial interaction with the vendor was required to create/negotiate custom-modifications, test them, and implement them. Accordingly, departmental procedures had to be examined and revised to meet computer system requirements. Due to the "customized" character of the System, software testing was much more complicated and strenuous than it would have been for the off-the-shelf software and, in fact, is not complete to date.

As soon as software is fully developed and documented we expect to put the entire system into productive use. We have already tested many of its system's major functions at some length. Training of personnel on site is continuing and acceptance of the new system does not seem likely to present a problem as "uptime" has improved and vexing "bugs" are eliminated.

Because of the complexity of its operation it is hard to measure or even estimate the total impact of RCS on our department. We have cooperated with our colleagues at the University of Washington to develop methods which have been used to establish a departmental performance baseline (1). We plan to repeat these studies, at our own and at a control hospital, as soon as the system has been in productive use in its entirety long enough for an equilibrium state to be reached. We hope this study will vindicate us in our decision to acquire the RCS.

Beyond the study and the present plans are some interesting

issues and opportunities. We see in the RCS the potential to both learn and teach better radiology technique and practice. The immediate problems of technical quality assurance and need to review of radiographic diagnostic accuracy efficiently are straightforward. More thorny ones loom in the future. We would like to use our system to generate a data base which could tie referral criteria to radiographic outcomes, and to critical diagnostic confidence levels of the referring physicians. We also see the future ability to interact with other systems within the University and hospital network for the exchange of key data of interest to each system for resource allocation or patient management strategies including development of multidisciplinary diagnostic protocols.

The technical revolution in radiology is not limited to image generation, but will eventually encompass data and processes of all kinds. We see our system as part of a milestone along the pathway toward this integration at our Center.

REFERENCE

1. Evaluation of the Impact of a Radiological Computer System on a Department of Radiology. Summary report for phase I by Center for Health Services Research and Department of Radiology, University fo Washington. Contract No. 223-80-6002, Bureau of Radiological Health, Food and Drug Administration USPAS, September 8, 1980.

A COMPREHENSIVE RADIOLOGY DEPARTMENT SYSTEM -- AN INTEGRATED APPROACH

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ABSTRACT

A fully automated and comprehensive Radiology Department system was implemented in the Fall of 1980, which highly integrates the multiple functions of a large radiology department in a major medical center. The major components include patient registration, film tracking, management statistics, patient flow control, radiologist reporting, pathology coding, and billing. The highly integrated design allows sharing of critical files to reduce redundancy and errors in communication and allows rapid dissemination of information throughout the department. As one node of an integrated distributed hospital system, information from central hospital functions such as patient identification are incorporated into the system and reports and other information are available to other hospital systems. The system is implemented on a Data General Eclipse S/250 using the MIIS operating system.

Computer systems to assist the management of various aspects of the radiology department have been reported for more than a decade. Many of these have emphasized a particular aspect of the department, such as reporting or file room management. Few systems, however, have provided a fully integrated and comprehensive set of functions which reduce the redundant information

processing occurring throughout the department and provide rapid communication among the various radiology sections. Furthermore, most systems lack important interfaces to key systems outside of the radiology department. Reported here is the successful implementation of a newly developed and commercially available comprehensive radiology department system which functions as one node in an integrated yet distributed hospital information system.

INTRODUCTION

The University of California, San Francisco, has taken a different approach to computerized Radiology Management. In 1979 specifications were written for a Radiology and Medical Records system. A bid was accepted and an integrated system was implemented; Radiology in the fall of 1980, Medical Records in the spring of 1981. This system is run on a Data General Eclipse S/250 computer with a MIIS operating system. This system is networked with three other hospital computers including the hospital patient identification and registration (PID/R) system. This network uses a microprocessor-based local area communications network technology with fiber-optic cable linkages developed by the Applied Physics Laboratory of the Johns Hopkins University. The network is the first of its kind to be implemented in a hospital and the Radiology system was one of the first two systems linked with this technology.

Systems, other than Radiology, currently in the network are:

Medical Records including Discharge Summaries and Operative Notes

Pathology

Patient Identification/Registration

Clinical Laboratory

Outpatient Pharmacy

Future networking plans include:

Clinical Ambulatory Record

Nursing Unit Display

Operating Room

Microbiology

Financial

The Radiology system is composed of registration, film tracking, transcription and pathology coding modules. Billing and statistics are by-products of the system.

REGISTRATION

All patients are registered by a CRT transaction. The patient identifying and account portions of the registration are obtained through the network. At the point of registration a multiple part form is automatically generated on a character printer. This form is composed of a technologist card, a darkroom identification card, an alternator card and a patient transportation card.

The Technologist Card is filled out by the technologist at the end of the examination. The technologist must indicate if the examination was done as requested or changed, exam start and finish times, exam room used and his/her user code.

The Darkroom Identification Card is used to imprint patient demographic data on to the radiograph. Our form is designed to be used with daylight as well as conventional systems.

The Alternator Card follows the radiograph through the process and identifies for the radiologist and referring clinician on which alternator panel the films have been placed.

The Transportation Card is sent back to the ward with the patient and confirms for the ward which examinations were done.

Other options in the registration module are:

ARR - ARRIVE PATIENT

CAN - CANCEL AN EXAM

CHN - CHANGE PATIENT NUMBER

CRT - CREDIT PATIENT ACCOUNT

DBT - DEBIT PATIENTS ACCOUNT

DEL - DELETE PATIENT NUMBER

EEC - EDIT EXAM CODE

EID - EDIT ID CODE

LST - DAYSHEET LISTS

NAM - GET PATIENT NUMBER FROM NAME

PEL - PATIENTS EXAM LIST

RPT - REGISTER PATIENT

RUN - DISPLAY RUN NUMBERS

FILM TRACKING

At UCSF we have elected to do all film tracking by CRT by CRT transaction. Film tracking is a controversial topic with many institutions choosing bar codes and optical readers. We believe that the speed and reliability of the CRT is sufficient for our needs. The geographical design and file room operation in our department were also instrumental in choosing this method.

When the patient is registered, labels are automatically generated in the file room on character printers. These labels notify the file room that the patient has entered the department. The labels indicate current date, and examination to be performed, date of last examination and file room location of master jacket. These labels are used for the master jacket and anatomical insert.

Other options in the film tracking module are:

ASK - ASK IF PATIENT HAS FILMS CHECKED OUT

DCS - DAILY CLINIC SCHEDULES

EDC - EDIT DOCTOR CODES

IN - CHECK IN FILMS

LST - LIST OF FILMS OUT TO A DOCTOR

MAIL - MAIL OUT FILMS

MSG - MESSAGE TO OTHER FILE ROOM

NAM - GET PATIENTS NUMBER FROM NAME

OUT - CHECK OUT FILMS

OSI - OUTSIDE FILMS

OVR - OVERDUE LIST

PRT - PRINT LABELS

RES - RESERVE FILMS

TRANSCRIPTION

Radioligists dictate in the normal fashion. Reports are keyed in on work processing units by Radiology transcriptionists. A "rough draft" copy of the radiologic report is generated on a high speed line printer and sent to the Radiologist. The Radiologist then initials the rough draft as correct or modifies it and returns it to transcription. If changes have been made, a second rough draft is generated on the word processor using the text editing options.

Rough drafts approved by Radiologists are then verified using a CRT transaction. The user code of the Radiologist is entered into the system by the transcriptionist, indicating the Radiologist as the verifier. This information is printed on the final report.

Four original final reports are printed which are distributed to Medical Records, Radiology File Room, referring Physician and Billing with no signature. These reports are generated in batch form in terminal digit order for Medical Reocrds and Radiology. Referring physician copies are generated in alphabetical order for prompt delivery.

Other transcription options are:

BEG - BEGIN A NEW REPORT

DEL - DELETE A REPORT

EDT - EDIT EXISTING REPORT

LOP - LETTER OPTION

LST - PRODUCES SEVERAL LISTS

PEL - PATIENT EXAM LIST

PRT - PRINT REPORTS

RPT - REGISTER PATIENTS

VER - VERIFY REPORTS

PATHOLOGY CODING

We have chosen the American College of Radiology Diagnostic Index for pathology coding. The Radiologist has two options when coding. He can dictate the ACR code at the point of initial dictation or write the ACR code on the rough draft. In both cases the codes are entered into the system by the transcriptionists.

Other options in the pathology coding module are:

ADD - ADD PATIENT ACR CODE

CHN - CHANGE PATIENTS ACR CODE

DIS - DISPLAY PATIENTS UNDER AN ACR CODE

EPC - EDIT PATH CODE

NMD - NUCLEAR MEDICINE DISPLAY

PEL - PATIENT EXAM LIST

XOD - X RAY, OP NOTES AND DISCHARGE SUMMARIES

BILLING

Once the technologist cards are completed they are returned to a receptionist for the data entry. An incomplete Statistics program is run daily to identify patients who have not had complete data entered. Once the examination data is complete it is transferred to the IBM 4341 financial computer by magnetic tape. This transfer occurs every twenty-four hours.

STATISTICS

Many monthly reports are generated. Some of these include:

Room Utilization

Technologist Productivity

Examination Date

CT Scanner Utilization by Patient Category

Average Length of Selected Examination

Other valuable reports which can be generated daily, weekly or monthly are:

Number of Reports Generated by Each Radiologist

Number of Final Reports Generated Without Twenty-Four Hours of Patient Examination, Twenty Four-Forty Eight Hours and More Than Forty Eight Hours

Patient Waiting Times by Examination by Cost Center

Example:

WAITING TIMES

Cost Center: 421

	Exam(s)	Description	Total over 30 min wait
04/05/82	001	Chest PA and Lat	10
	002	Chest PA Only	1
	048	Abdomen-KUB Only	1
	057	GI-Upper-DBL Contr	1

Because of the interface to Medical records a Radiology Audit program is available. This audit requires the following date input:

Date of Audit:

Requested By:

Audit Dates:

Exams:

The audit produces all radiologic impressions for those selected dates, post operative diagnosis and discharge summary. This program aids in correlation of interpretation as well as provides information for JCAH and state or federal audits.

COST

As hardware and software are shared by Medical Records, Pathology and Radio-

logy, it is difficult to allocate specific Radiology costs. A close approximation is as follows:

PRODUCT	VENDOR	UNIT COST	TOTAL
Software	Custom Medical Systems (appl) Meditech (Oper, System)	$ 50,000 ++ Extras	$ 50,000
Main Hardware	Data General	$ 65,000	$ 65,000
CRT's (16 Units)	Perkin-Elmer	$ 1,600	$ 25,600
Character Printer (5 units)	Qume	$ 3,000	$ 15,000
Word Processing Units (6 units)	Megadata	$ 3,500	$ 21,000
Communications Equipment (27)		$ 500	$ 13,500
Line Printer (1 unit)	B D S	$ 8,000	$ 8,000
		System Total	$198,100

Monthly Maintenance costs are:

	Unit Cost	Total
Service Contract on Hardware	$ 630.00	$ 630.00
CRT's, Character Printers (21)	$ 25.00	$ 525.00
Word Processing Unit (6)	$ 55.00	$ 330.00
Line Printer (1)	$ 110.00	$ 110.00
Software Maintenance	$ 400.00	$ 400.00
Telephone Line Rentals (28)	$ 4.50	$ 126.00
Total		$2,121.00

ADVANTAGES

There have been many benefits to the department as a result of implementing a computerized radiology management system:

Minimize Clerical Effort

Increases Patient Throughput

Increases Availability of Patient Information

Improves Charge Capture

Provides a Retrievable Data-Base for Research and Teaching

Allows Audit of Clinical and Management Performance

System Problems have been:

Maximizing Use of Statistical Information Available.

Employee Training:

A. Instruction in the Integration of Each Part of the System

B. Building Employee "Trust" in the Computer Through Increased Knowledge of its Functions and Capabilities

C. Providing Constant Assistance for Employees in Changing From Instinctive Manual Information Retrieval to Use of Computer Information

SUMMARY

An integrated computerized Radiology and Medical Records System has been successfully implemented at the Unviersity of California San Francisco.

COMPUTER SYSTEM AT LOUISIANA STATE MEDICAL CENTER

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Taken over only six years ago by Louisiana State University, the 500-bed LSU Medical Center in Shreveport might best be described as an institution that is "coming of age" in both the clinical and the academic senses. A vital part of the institution is the expanding department of diagnostic radiology, in which 11 staff radiologists, 9 residents, and 40 technologists perform about 95,000 procedures each year. Supporting our goals of quality treatment and expert training is our department's computer. As part of a hospital-wide health care information system from Shared Medical Systems, it combines smooth, day-to-day management of the radiology department with extensive reporting capabilities that support administrative and academic functions.

The computer system has helped us tighten up a department which was poorly organized and controlled. Now, when physicians order radiology procedures on their patients, the requests (which can be entered on any terminal in the hospital) are automatically printed in the radiology department. This permits us to effectively schedule patients in advance and allocate examinations to appropriate rooms, as well as identify the appropriate film jackets to be pulled before the examinations are complete. This minimizes downtime and unnecessary patient waiting. We can instantly identify "no shows", of which we, unfortunately, have a high percentage, and thus can explain to irate physicians that the examinations that cannot be found were simply not performed. Order entry also allows for automatic notification of ancillary departments - such as dietary and escort - about their roles in assisting individual patients.

When patients arrive in the Radiology Department, appropriate patient information already in the computer is promptly brought up onto the terminal

screen. After briefly verifying the information, the patient is registered with the touch of a button. If additional registration information is needed for a given patient, we can easily enter it using the same terminal. In addition to speeding patient registration, automation eliminates the substantial error rate that is an inherent problem in manual registration.

Prior to automation, patient flow and whereabouts presented substantial and time-consuming problems. Patients often experienced long delays as clerks searched for old film jackets in two busy file rooms which were located far apart from each other. We now can locate old films instantly, simply by asking the computer to display the precise storage location as well as the dates and types of previous procedures performed on the patient. Many hours that were formerly spent vainly searching for film jackets can now be saved.

Prior to automation, procedures that have been performed on an outpatient basis were sometimes unnecessarily repeated on the same patients once they had been admitted to the hospital. Now, each new examination is promptly included in the patient's data base, so that a complete record (up to 42 examinations) of previous studies is kept current and immediately available. Requests for unnecessary repeat examinations can thus be easily spotted, an extremely difficult task with a manual system.

Once a patient is registered and his records located, the system continues to expedite his orderly movement through the Radiology Department. The receptionist has constant access to a current list of waiting patients so that she can always determine who is next in line. By calling for a film quality status report, the receptionist can easily tell which examinations had been completed and, therefore, which patients may be dismissed. The receptionist also has constant access to the most current data on unread examinations, a feature that eliminates the threat of delaying or overlooking the reading of certain

studies.

One system feature that we have not yet implemented, but which completes the radiology procedure cycle, is automated results reporting. As a result of integrated data processing and word processing, the system can improve transcribing productivity and at the same time allow for swift communication of results to nursing stations or other hospital locations.

The value of an automated system has not been limited to tracking of patients and films throughout the department. Prior to automation, maintenance of an orderly film filing system was extremely difficult and film indexing and checkout records were nonexistent. Because the hospital staff doubted that they would ever be able to find a film once it had been caught up in the maelstrom of the radiology department, a majority of films were stolen, and understandably so.

Today, the patient file locator helps physicians and radiology clerks save time in finding film jackets. The automated system provides for a much faster checkout procedure. All that is required to check out a film jacket is for the radiology clerk to pass a reader wand over the bar code on the film jacket. Large numbers of films can be sent to the clinic at one time with tight control and without need for manual recording of patient identification numbers.

Even at night, when we have less control over compliance of rules for borrowing films, the simplification of these procedures is encouraging staff members to check out films correctly. An important correlary feature is the ability to send dunning letters to physicians who retain borrowed films more than 24 hours. An automated succession of dunning letters is available, ranging from mild reminders to thinly veiled threats.

Computerization has been of great value in managing the Radiology Department. The historical file that stores our data enables us to integrate patient

demographic, diagnostic, and other file information (currently on more than 50,000 discharges) with such data as age, sex, medication, radiology procedures performed, complications, etc.; and because charges are automatically captured and available to the Business Office as soon as a procedure is ordered, revenues have increased and manual billing time has been eliminated. Personnel, budget, equipment, inventory, and other resources can all be utilized more efficiently through automation. Without automation, the multitude of reports required by both the JCAH and our own administration were prepared at a painfully slow pace, because data collection, statistical computation, and analyses were done manually. Simply compiling information for daily, monthly, and annual reports of the number of radiographic procedures performed at LSU Medical Center was nearly a full-time job. Today, with our data base system, the results are available in a fraction of the time, with far less effort, and a reduction of our clerical needs by at least 20%.

Let me now illustrate some of the special reports that can also be done based on the results of routine data entry already in the system. These reports are especially helpful in management of the department. For example, we have been given permission to purchase an additional unit for our Walk-In-Clinic, and are in the process of deciding whether a bone or chest unit would be of more value. We are, therefore, conducting a special study, based on information already in the system, that will indicate the ratio between bone and chest examinations, not only within the entire department but also within the specific Walk-In-Clinic. Selection of our new radiographic unit will thus be based on solid facts, rather than on guesswork. Because we have easy access to the distribution as well as the numbers of all other types of examinations performed in the radiology department, future proposals for additional space, staff, or equipment can be more easily justified.

Special reports can aid in utilization studies in the Radiology Department. For example, we recently learned that one-fourth of our total yearly volume consisted of portable examinations. We are now breaking these statistics down by nursing station, ordering physician, and other categories to determine whether the bulk of these portable examinations were justifiably performed, such as for patients in the Intensive Care Units or in traction, or whether certain staff members or nursing units are ordering an inordinate number of portable studies with the consequent unnecessary and inefficient use of radiology equipment and personnel.

Discrepancies in statistics help us identify the number of "no show" patients whose examinations were cancelled. Somewhat like the airline industry, we will be able to "overbook" and to better schedule our resources by tailoring the number of scheduled examinations to reflect the average number of "no shows". By analyzing departmental revenues and comparing chargeable fees to money collected, we can identify potential sources of improvement in our financial and billing systems.

By analyzing the ordinal ranking of procedures by volume and percent of total examinations as well as by charges and percent of total charges, we can determine the most profitable areas of the radiology department and convince the hospital administration that additional resources should well be channeled into these areas.

Availability of a computerized system may permit the establishment of clinical utilization studies which would be unwieldy using manual techniques. As an example, we recently were informed that the Psychiatry Department was ordering a battery of radiographic examinations on all patients admitted to their inpatient service. In addition to routine admission chest x-rays, these patients were subjected to skull series, thyroid function, brain scans, and CT.

examinations. Using the computer data base, we identified 100 inpatients who had been seen on the psychiatric service and had received this battery of radiographic tests, a task which would have been almost impossible using a manual system. By analyzing the results of these examinations, we conclusively proved the utter futility of all of these routine studies, with the possible exception of a C.T. examination in a patient with lateralizing signs.

With this data in hand, we were able to convince the staff of the Psychiatry Department to desist from these wasteful practices. In addition to substantially decreasing patient exposure, eliminating these routine examinations will save the Medical Center more than $50,000 per year. Whether studies such as this are based on sampling or on the total population, the elimination of exhaustive manual file searches makes it much more likely that we will perform similar clinical audits in the future.

The vast storage capacities of the computer will also enable us to perform utilization and patient referral studies on extensive populations. One prospective study currently being performed addresses the perennial question of routine chest radiographs in such diverse areas as routine hospital admissions, routine preoperative studies, and routine pre-employment chest examinations. In addition to helping cost-conscious adminstrators reach an accurate conclusion, we expect this study to aid in ensuring that no individual receives either more radiation or less required examinations than is medically necessary.

We are currently in the process of coding x-ray result categories so that future reports can be formatted to include statistics on examinations that were normal, abnormal but clinically insignificant, or significantly abnormal, as well as specifying the precise abnormality in this last category. Other areas

of the optimum number and types of radiographic projections required to give all essential diagnostic information for a variety of procedures and complication studies analyzing the relationship of angiographic complications to such factors as time of procedure, type and volume of contrast, type and size of catheters, and specific arteries catherized.

The huge storage capabilities of the computer can be of great value in developing an extensive, easily-accessed teaching file system without the need for extremely expensive reproduction of huge numbers of radiographs. Using the American College of Radiology's codes of body site and diagnosis, we will automatically code all radiographs containing substantial abnormalities so that illustrative cases may be located quickly when needed without having to reproduce them. This can save untold hours that are now spent leafing through x-ray reports and teaching file cases in search of interesting films for lectures and scientific papers. Of additional importance is the ability to immediately access teaching file films by both body site and diagnosis, unlike manual systems and regular teaching files for which only a single approach would be practical.

Thus, the radiology computer management system serves a multitude of functions, including patient flow, film lending, results reporting, and report preparation, as well as being a valuable tool for resident teaching and clinical research. As the Radiology Department at the Louisiana State University Medical Center comes of age, having a computer that grows with us is vital.

COMPUTER ASSISTED RADIOLOGY PATIENT INFORMATION SYSTEM

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System Design

Since the fall of 1972 all in-patients and Health Sciences Clinic patients of the University of Alberta Hospitals have been registered in the PDP15 computer shared information system. Two files are maintained in the system for patient information, the active master file and the Central Registry file.

When a patient is registered in the system the active master file which contains the patients detailed demographic, service and accounting information is created. Simultaneously the Central Registry file is created and contains the patient's name, sex, date of birth, Alberta Health Care Insurance number, admission date and discharge date. The last date on which the patient visited the Health Sciences Clinic and/or Radiology will also be stored in Central Registry.

Due to the storage limitations active master files on in-patients are removed from the system approximately 35 days after discharge, and for Radiology out-patients are removed approximately 45 days after the examination is entered into the system. The Central Registry remains as a permanent record.

Equipment

The Radiology Computer Hardware consists of:

- Seven terminals
- Six printers
  - two bar code printers
  - one normal report printer
  - two patient identification marker card printers
  - one lists printer
- Four bar code readers and light pens

Access and Security

In order to gain access to the computer and the Radiology programs, each user must sign onto the system. To sign on the user requires:

1. A password, for access to the computer.
2. A system identification code which specifies which module of the system (eg. Radiology, Admitting) the user wishes to access. (Users know only their own department code, therefore can't gain access to other user department programs).
3. A user code which identifies the user to the computer.

Individual user codes are assigned and entered by the system manager. Each user is also assigned a user privilege code determined by the routines they are required to execute.

This privilege code limits the user's access to the routines. The user's name is registered in the system and will be displayed on completion of each routine. When errors occur, the user can thus be identified.

Application

The Computer Assisted Radiology Information System was designed to perform the manual clerical functions carried out by the clerical staff in the Radiology Department.

A number of events must occur when a Radiology consultation form is received .

The first step is to ensure that the patient is in the system. If the patient is an in-patient the record will be in the system, as a unified patient identification number will have been assigned by the Admitting Department. If the patient is an out-patient it will be necessary to search the system utilizing the Central Registry to determine if the individual has a previously assigned I.D. number.

If the patient has an I.D. number, it is used for all current and future visits. If the patient cannot be found in the system, a unified patient identification number is assigned.

The second step is to complete all applicable computer routines. There are thirteen major routines in the Radiology system, with some routines having several options:

Wait List Routine

As requisitions are required to be delivered to Radiology 24 hours

before the procedure is to be performed, the "wait list" routine is generally the first completed. This routine allows procedure requests to be entered onto a "wait list" and has the option of printing marker cards and sending printed labelled bar code messages to the Film Library, notifying the clerks that previous files and/or a new file is required. Procedures entered in this routine automatically appear in the status routine.

Log Exam Routine

When a patient actually arrives in the Radiology Department, the receptionist utilizes the log exam routine. This routine is designed for procedures on the wait list to be logged to the patient's file. Procedures can only be logged if the date on the "wait list" corresponds to the date the procedure is being performed. There are, however, some users in the Department who have special privileges recognized by the program, enabling them to post log a procedure. When a procedure is logged the information is automatically updated in the status routine. The actual time the entry is made is added by the system. Logged procedures will appear on the daily log and the daily statistics.

Emergency Documentation Routine

The Emergency Documentation routine is designed for the documentation of procedures performed in the Emergency Radiology area.

Procedures entered via this routine automatically appear in the status routine, on the daily log and on the daily statistics. This is a shorter

routine which incorporates the logging procedure. It also prints a marker card and sends a message to the Film Library.

Status Routine

The Status routine is designed to provide easy access to those features of a patient's history most commonly referenced by the radiology staff. This routine will display any procedures on the "wait list" indicated by an asterisk after the procedure, plus any logged, cancelled or reported procedures. Film loans will also be shown. This routine has a capacity for displaying eight procedures. The procedures are filed by date, with the most recent appearing at the top of the list.

The time field represents the time the procedure is logged. Printer generated normal reports are indicated by the letter "N". Procedures will be purged from the file approximately forty-five days after the date the procedure was completed.

This routine does not permit any changes to be made to the patient information, but simply displays information in the system. No hard copy is available.

This routine is very heavily utilized by the control technologist in response to requests from the nursing units and by the file clerks at the Library Loan door in checking the patient's status file for physicians wishing to view films.

Cancel Exam Routine

The Cancel Exam routine is designed for logged procedures and procedures on the "wait list" to be cancelled by the receptionist. The only field into which new information can be entered is the remarks field. This free text field allows the user to enter the reason for cancellation of the procedure. When a procedure is cancelled the information is automatically updated on the status file. Cancelled procedures are moved to the bottom of the list of procedures being displayed. Logged procedures which are cancelled do not appear on the daily log or the daily statistics. A hard copy of all cancellations is run daily.

Edit Log Routine

The Edit Log routine is designed for editing of procedures which have been logged, but not reported, into the system.

When the procedure is changed the information is automatically updated in the status routine, on the daily log and on the daily statistics.

Film Traffic Routine

The Film Traffic routine is designed to track all films which leave the Radiology Department via loan requests. These range from films taken by a Radiologist for reporting, to any other physician or hospital requesting film files.

This routine has four options: The Check Option. is designed to view

the status of the film file and display whether the films are available in the Department or have been loaned out. If the films are loaned out the system will indicate when and to whom. This routine does not permit any changes to be made to the patient information and no hard copy is available.

The Loan Option. is designed to record the loan out of the film files from the Film Library. The only loaned out files not entered into the system are those going for immediate viewing. The "TO" field can be entered either with the light pen and bar code or manually. The patient field also can be entered by utilizing a light pen across the bar code on the file envelope, or manually by inserting the I.D. number or the patient's name if no bar code is available.

The Remarks field allows for entry of any comments regarding the loan out. Entries made via the loan out option are automatically set up for viewing in the status routine.

The Return Option. is designed to record the return of all film files to the Film Library. The patient field may again be entered utilizing the light pen when applicable or manually. When the return option has been completed the loan out record is removed from the patient's status file.

X-Ray Report Routine

This routine is designed to queue and print identification headers on continous x-ray report forms. In addition the routine is designed to print

normal radiological reports by drawing information from the normal resource file. This system allows for queuing of patients under a specified procedure and radiologist. There are approximately eighty normal reports generated per day. At present we do not generate identification headers for abnormal reports.

List Routine

This routine is designed to produce on demand various hard copy statistical reports and lists from the system. Each report will be captioned with an appropriate header identifying the report, the date and the time the report was printed. This routine does not permit any changes to be made to patient information.

There are a total of sixteen reports available to us:

Procedure Descriptions and Codes. This report is organized by broad procedure classes. There are eighteen procedure classes: Cardiac, Chest, Gastrointestinal, Genital Urinary, Head, Lower Extremities, Mobile Chest, Neuro, Nuclear Medicine, Operative Procedures, Portables, Skeletal Surveys, Special Techniques, Spine, Tomography, Ultrasound, Upper Extremities and Vascular. Within each procedure class the report lists each procedure carried out in the department. There are approximately seven hundred procedures on this list.

Area with Bar Code. This report lists alphabetically with bar codes all areas where films may be loaned.

Doctor with Bar Code. This report lists alphabetically with bar codes all doctors to whom films may be loaned.

Radiologists with Bar Code. List alphabetically with bar code all radiologists to whom film files may be loaned. These three bar code lists are run periodically from the bar code printer and then laminated for use in the Film Traffic Routine.

Cancel by Date. Lists alphabetically by referring physician all patients for whom radiological procedures have been cancelled. This list is printed daily and displayed at the loan out door of the Film Library for physician perusal.

Daily Log. Lists alphabetically by referring physician, each procedure performed in the Radiology Department, both main and emergency areas. This list is run periodically throughout the day and displayed at the loan out door of the Film Library for physicians perusal.

Daily Statistics. This report will be organized by broad procedure classes. Within each class the report will list each procedure and the number of in-patient and out-patient procedures completed on each of the three daily workshifts. Subtotals are provided at the end of each class and a grand total printed at the conclusion of the report.

Monthly Statistics By Source. This report is organized by source. For each source the report will list the total number of patients examined on each of

the daily workshifts. Separate subtotals are provided for the in-patient and out-patient sources and a grand total printed at the conclusion of the report. A yearly statistical report by source can also be generated.

Monthly Statistics. This report is an exact duplicate of the daily statistics report. The period of accumulated figures can be anywhere from two days to thirty one days. These two reports are run on the fifteenth of the following month and combined with a summary sheet constituting our month-end statistical package. A yearly statistical report by broad procedure classes can also be generated.

Normal Report. This report will be organized by broad procedure classes. Within each exam class the report will list by normal identification code, the normal reports currently used in the department.

Overdue Film Loans. This report will list alphabetically by borrower all films which are absent from the department after a specified period of time. The four overdue periods are over three weeks, over two weeks, over one week and less than one week. This report is run once a week and follow up letters are sent to the applicable borrowers.

Radiologists. Lists alphabetically all radiologists and residents with reporting privileges.

Doctors and Areas. These reports lists alphabetically all doctors and areas utilizing the film loan service. These lists are very seldom used.

Users. This report lists alphabetically or numberically all Radiology Department operators who have access to the Computer Assisted Radiology Information System. This list is run periodically as an update and is kept on file.

Wait List. This report lists alphabetically by referring doctor each procedure on the wait list. This list is run at the conclusion of each day shift and is cleared as there should be no patients remaining on the wait list for that day.

Copies of the Daily Log, Daily Statistics, and Cancel by Date are retained in binders and kept for one year.

Resource Routine

This routine enables restricted users to enter all Radiology resource files into the system. This routine has six options:

Area. This option is used to enter the name of each area to where files may be loaned. The computer then assigns the bar code.

Doctor. This option is used to enter the name of each doctor to whom files may be loaned. The computer then assigns the bar code.

Examinations. This option is used to enter and describe each examination or procedure in the system.

Normals. This option is used to place each normal report in the system.

Radiologists. This option is utilized to enter the name of each radiologist and resident with reporting privileges into the system.

Users. This option is used to inform the system of each operator who will have access to the system. For recall purposes the user codes once issued cannot be altered. There are four types of privileges for users and these are assigned at the discretion of the system manager. This resource routine is only accessible to five or six people in the Department. These individuals are responsible for the updating of the total resource package in the system.

The three remaining routines are Marker Card, Message to File Area and Reprint Message to File Area. The Marker Card and Message to File Area routines are designed for printing extra cards or messages when required. The reprint messages routine is designed to reprint on demand all messages printed for the previous 24 hour period.

Down Time

The system is down every evening for a maximum of one hour to enable the day's information to be transferred to a back up disk. Once a month the system is down for two to three hours for maintenance. Other than these scheduled down times there has been only minimal shut-downs. When problems do occur Information System's staff are very quick to respond and keep us posted as to their progress.

There are manual back up systems for all routines in the Computer and we revert to these during the shut-down periods. All manual functions completed during shut-downs are back entered in the system once it is again in operation.

Problems Experienced

As can be expected with any new system some problems have been experienced:

1. Initial reluctance to accept the system caused by inherent conservatism and a fear of loss of employment due to automation.

2. The frustration experienced by the users as a result of slow response time at peak periods. This slowness was due to the large number of user departments and has been eliminated by the addition of a larger computer.

3. System abuse: a) Doctors taking the films without following correct loan out procedures.
   b) Incorrect information being provided by users.

4. The problem of the creation of two files and two different I.D. numbers on a single patient. This is due to an inaccurate search and/or misspelling of the patient's name. This is not a difficult problem to correct, but, it does tend to be time consuming.

What has the System Done for Radiology

1. Streamlined the reception clerical procedures thereby improving the efficiency of the patient documentation, resulting in a decrease in patient time in the department.

2. Vastly improved accuracy of patient information.

3. Streamlined filing procedures, especially with the utilization of the bar coding for the film loan routine.

4. Enhanced the department's credibility with the medical staff.

5. Greatly reduced the time taken in the preparation of the monthly and yearly statistics as well as providing a much more accurate departmental statistical package.

6. Created a higher staff morale with a substantial decrease in the staff turnover and a more efficient use of staff in the Imaging Records section.

What Does the Future Hold?

The present system is being adapted for conversion to a "Tandem" computer system in the fall of 1982.

The Tandem computer is a system designed for uninterrupted working. It has

a dual processor/disk concept, therefore there is always back up should one fail. Due to the much larger storage capacity, the Tandem programs can be expanded in the future. We anticipate adding such routines as interpretation coding, appointment and room scheduling, patient control, expanded patient information base, pathological files, purging criteria for disposal of film files, routine administrative functions and a direct communication between word processing equipment and the computer. New user departments are being added, the latest being a Materiels Management program. After the move to the new building in 1983 we can look forward to the addition of individual nursing station terminals.

In conclusion we would like to summarize what, in our opinion, are the key factors in the successful development of a computerized Radiology Information System

1. The selection of a Radiology committee consisting of a co-ordinator and four to six key members, prepared to contribute hard work and total committment.

2. The cooperation of the Information Systems Department staff and the Radiology Committee in the planning and design of the system to make it workable for the user.

3. The cooperation and acceptance of all Radiology users. Their cooperation and acceptance is dependent upon the encouragement and support offered by the committee and co-ordinator through the initial planning and design stages and the training and implementation.

4. The total committment and degree of support offered by the Information Systems Department throughout the project. Our Information System's staff were extremely supportive throughout and are always available and willing to help solve problems.

5. Close working liaison between the Radiology Department and other departments sharing the system, such as Medical Records and Admitting, in order to maintain the accuracy of information.

6. The ongoing system maintenance to ensure that the system is functioning properly. The continual revisions of routines, addition of new and improved methods and the enhancements of programs.

7. The constant training and updating of all staff as the success of any computer system is user related.

Despite the hard work and long hours that will be involved in our conversion to the Tandem, we are very anxious, and look forward to the enhancements of the applications that the Tandem can provide in our Computer Assisted Radiology Information System.

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A CLINICAL ACADEMIC COMPATIBLE RADIOLOGY INFORMATION SYSTEM

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BACKGROUND

In 1979 the Department of Radiology, received an excessive number of complaints from referring physicians with regard to late radiographic reports and inability to locate films. A systems analysis pointed out problems in all management areas under the then existing manual operations. From this analysis the manual system was streamlined, and it was decided to convert from manual operations to a department-wide computer assisted management system.

A three-stage departmental computerization plan was designed and has been implemented over the past eighteen months. The stages are:

1) Development of a stand alone system for transcription using computer terminals and slave printers which can be integrated into a fully computerized departmental system.
2) Introduction of basic radiology management modules that include registration, film library, reporting, on-line report signature, sorting and printing, management and billing reports.
3) Use of bar code readers to further automate Stage 2 and the addition of physician generated direct reporting.

Prior to Stage 2 implementation, with the assistance of the Bureau of Radiological Health, a baseline work flow analysis was conducted. The Department will be resurveyed in the near future

to compare pre- and post-automation efficiency.

HOSPITAL AND MEDICAL PRACTICE

The Bowman Gray School of Medicine/North Carolina Baptist Hospital Medical Center is a teaching facility of approximately 700 beds with all specialties represented. The Medical Center has a central computer facility performing full Hospital and Medical School financial tasks and research capabilities but no automated patient information system. The Radiology System has been conservatively developed in terms of both cost and computer compatability to ease interface with an eventual hospital-wide system.

The Radiology Department is staffed by 30 faculty members and 27 residents. All radiological subspecialties are represented. The Department performs approximately 200,000 diagnostic examinations per year. It bills separately from the hospital through an in-house service bureau, the Department of Clinics, which produces all professional billing for the institution.

SYSTEMS SOFTWARE

The Radiology Management System was developed by Smith, Dennis and Gaylord, of Santa Clara, California, for the Bowman Gray School of Medicine/North Carolina Baptist Hospital as a highly-flexible, on-line, interactive system. Their prior

Table 1

HARDWARE

HP 3000, Series 33 with 768K of Memory		$ 58,625
120 MegaByte Disc Storage		21,000
1600 BPI Tape Drive		12,585
13 HP 2640 Series Terminals		45,500
12 Televideo Terminals		11,400
4 HP Printers		14,400
10 Anadex Printers		12,950
31 FCP 22 Computer Identics Bar Code Readers With Keyboard		24,520
12 FCP 12 Computer Identics Bar Code Readers		9,250
3 Multiplexors		10,750
	TOTAL	$ 220,980

radiology experience and computer expertise was coupled with continuing involvement of the Radiology faculty and staff to develop a system which automates the functions of a large hospital radiology department while also providing the teaching and research tools desired by a medical school. The resulting system permits simultaneous access by many users in a multi-terminal/multi-printer environment. The Hewlett-Packard 3000 Series of computers drives the system. (For hardware listings see Table 1).

Smith, Dennis and Gaylord's Technical Resource Module (TRM/3000) was used in the development of the System. TRM/3000 is a standard methodolody for structured software development. TRM's tools provide design, program, documentation, performance, support and use guidelines specifically tailored to the optimal use of HP 3000 computers. These protocols allow for much of the

flexibility built into the System including the ability to easily make screen, sorting and other common revisions.

TRM/3000 also allows cost savings by supporting the terminals of four different manufacturers in any mix, permitting selection of equipment that fits both needs and budgets. Due to the standardized interfaces permitted by TRM, additional equipment may be added. The software is in compiled BASIC and is easily transferred to other medical environments.

DESCRIPTION OF SYSTEM

The application software is composed of four major modules each of which serves a different department function.

Admission/Registration Module

At six (6) entry points in the Department of Radiology the patient admission/registration module is utilized. The main features are:

1) Access of existing patient information by:
    a) Name or first four letters acronym.
    b) Hospital unit number.
    c) Requisition sequence number.
2) Basic patient information acquired and kept on-line includes:
    a) Name and verifying demographics.
    b) History of prior service including date, exam and referring staff are also listed.

The completion of the registration process triggers printing of an adhesive bar code label (requisition sequence number) which is affixed to the requisition form. Simultaneously in the appropriate file room, a message alerts personnel that the patient is in the Department and then gives the location of the master folder. If the patient has not been previously radiographed, information is provided for a new file jacket. In addition, a bar code label is produced which represents the patient's hospital unit number and is affixed to the patient's permanent master film folder.

Patient Status Module

In this module, the System captures information detailing examinations done, film used, and time required for the procedures. In addition, a referring physician can query the System and determine the location of his patients's master folder, the exact location of the patient and whether an examination has begun or has been completed.

Bar code readers are located outside all examination rooms. Using the bar coded requisition, the technologist enters the bar codes representing the patient requisition number, examination room number and technologist number. At the completion of the examination and the patient exit, additional strokes record the examinations performed and film used. The bar code on the patient requisition is then stroked again, closing the file on that particular examination. Film utilization and examination

bar codes are located in laminated folders adjacent to the examination rooms.

Film Library Module

After quality control, the new films are matched with the master folder in the file room. From the file room the folder is dispatched to the subspecialty interpretation area. As the films are loaded onto the alternator, a bar code on the viewer is stroked, and, the bar code affixed to the film jacket is then stroked, completing computerized film folder location update. Inquiry from any terminal in the System will then show the exact location of the patient's master folder.

Check-in and check-out of films for physicians is accomplished with a bar code unique to each physician which is laminated to a plastic card. During film check-out, the card and jacket are stroked to provide location and personal responsibility for the checked-out films. A stroke of the jacket upon return logs in the films. An exception report identifies film jacket delinquencies of over 24-hours.

Interpretation/Reporting Module

This module has six subsections: staff reporting/approval, resident approval, bar code generated reports, inquiry function, research case identification and printing/sorting.

With the requisition and film ready for interpretation, the radiologist selects one of two methods of reporting:

1) Bar code generated standard expressions.

2) Conventional dictaphone dictation.

With the conventional dictation method, the radiologist dictates to tape; the tape is transported to the transcription area and typed on-line. Once typed, the report is available on any terminal in the Department as a preliminary unsigned report.

Inquiry Function. All preliminary reports are available on-line for review and approval. The radiologist, using a double security code, may access his reports singly or in sequential order, first in - first out basis. Then all patient information and the typed report are displayed. The radiologist types "Y" to indicate "Yes" if the report is correct. The report is then considered signed and becomes available in the System as a signed report and is ready for printing. When the report is printed it reads "Signed by Dr. XXXX".

If there is an error in the report the radiologist strikes "N" for "No", or disapproval. The report is printed for modification and returned directly to the reporting radiologist. After modification, a transcriptionist calls up the report and corrects the error. The report is again presented to the radiologist for on-line approval.

A third option is available to accommodate times when a faculty member is unavailable to sign his/her reports. An authorized faculty member may call up, review and approve these reports by striking "X" on the terminal. The computer is thus

directed to approve the report and prints "Report Reviewed and Approved by an Appropriate Faculty Member." The name of the dictating physician is retained in the header information. The Part "B" Medicare intermediary for North Carolina has accepted the above signature methods as documentation of services rendered.

Resident Approval Module. To accommodate the teaching aspects of the Department a resident approval module is included. After entering a double security code the resident, in like manner, may call up one or all cases. He/She may approve or disapprove, but these decisions do not trigger a final report. If the resident approves, an asterisk ("*") on the report communicates to the faculty member that the report has been reviewed and approved by the resident. When the resident disapproves, an "E", for error, is generated on the report screen. In all cases the faculty member makes the decision for final approval or disapproval as described above.

Bar Code Generated Reports. At interpretation stations there are bar code readers attached to each terminal. Each faculty member or group may have their personal or group standard expressions in the System. If the radiologist determines that his/her standard expressions can be used in a case, he/she strokes the bar code on the patient requisition and the patient information is displayed on the terminal. He/She may then generate personally or sectionally defined standard reports by stroking the standard report bar codes. There is also an option

for entry of free text through the keyboard. The report is then displayed on the terminal and can be reviewed and approved. This process generates a signed report while bypassing manual transcription. It is immediately queued for printing and is accessible at any terminal in the System as a final report.

Research Case Identification. The System allows several methods for the identification of research or teaching cases. ACR codes or individual identifiers may be:

1) Dictated using the conventional transcription method.
2) Entered through terminal keyboard during bard code generated reporting.

Any number of codes may be used on a case and coding may be easily changed or updated by the faculty member.

Printing/Sorting. Twice daily the approved reports are queued for printing. The System includes a flexible sorting program which allows reports to be sorted by the following:

1) Referring M.D.
2) Floor/Ward.
3) Patient unit number.
4) Transcriptionist's code.

The user can instruct the System to perform the sort routine desired, and thus have the sorted copies printed, and ready for distribution. This function reduces the clerical time required for collation and has proven to be a cost-saving process.

Management Control

By-products from the modules of patient registration, patient tracking and report transcription can be captured and summarized on a timely basis to better manage and control our department. The framework for our management reporting can be summarized in three categories:

1) Daily management.
    a) Exception reporting (incomplete work-in-progress).
    b) Billing.
    c) Daily activity.
    d) Overdue film reject report.

2) Operation management.
    a) Room/machine utilization.
    b) Workload/revenue analysis.
    c) Exam turnaround.
    d) Film reject/film utilization analysis.
    e) Shift analysis.

3) Personnel management.
    a) Technologist productivity.
    b) Physician productivity.

SUMMARY

We have designed and implemented a computer-assisted management system for radiology departments. We believe that it has the flexibility to be useful to departments of varying sizes.

It may be used in toto or separated into component parts to meet the needs of various users. It is relatively small and inexpensive but is specifically designed to be able to interface with larger systems when desired.

RADIOLOGY COMPUTER SYSTEM AT ELMHURST HOSPITAL CENTER

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ABSTRACT

A sophisticated x-ray file management and reporting system is installed in a large municipal hospital. The management of the installation and training proves as important as hardware or software.

BACKGROUND

Elmhurst hospital is a 772 bed acute care municipal hospital in New York City. It is the fourth largest of New York's fourteen (14) municipal hospitals, and is located in a polyglot neighborhood containing Hispanic, Indo-Pakistani, Chinese, Black, Korean, Thai, Vietnamese, Russian and Greek populations. Ten to twelve per-cent (10-12%) of our patients are illegal immigrants.

Elmhurst serves as receiving center and hospital of last resort for a population of approximately one million. Eighty-five per-cent (85%) of admissions are emergencies. We have

a large clinic population.

Radiology performs 125,000 examinations per year. We have seventeen (17) fixed x-ray units, a single ultrasound room, and an assortment of portables. The Department is staffed by full-time salaried attendings who are faculty members of the Mount Sinai School of Medicine. The Radiology residency is integrated with the Bronx VA and Mount Sinai Hospital, and has an authorized level of thirty-nine (39) trainees. Residents rotate monthly, and spend approximately twenty per-cent (20%) of their time at Elmhurst.

Elmhurst had one of the first General Electric Raport systems (1974). Raport was poorly maintained, no investment was made in software up-dates, and the system was leased for the purpose of saving money by eliminating all transcribers. When General Electric abandoned Raport, a request for a Certificate of Need and funds for a new "automated reporting" system were filed.

In July 1980:

a) The lease on Raport was about to expire.

b) There were no typewriters, no dictating machines, and no trascribers in Radiology. (To force the use of Raport)

c) The Board of Estimates had appropriated funds to purchase an "automated radiology reporting system". The terms of the appropriation were that the physical components of the system had to be on premises by June 30, 1981 and that it must produce reports without the intervention of a transcriptionist.

d) There were no funds appropriated for: construction, support personnel, telecommunications, furniture, or software leasing.

e) Our hospital management was cooperative and truly eager to do something (within

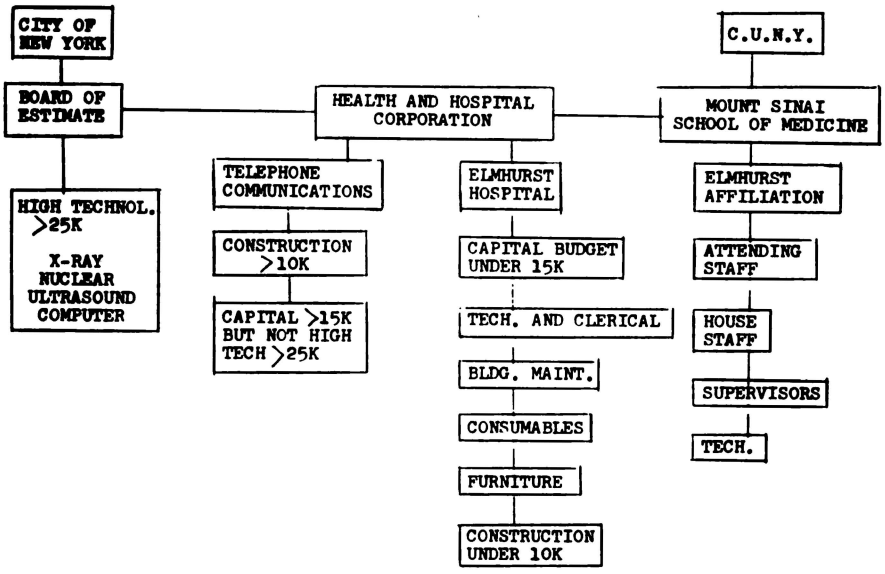


Figure 1

the constraints imposed upon them by the City of New York, the affiliation agreement, the State and Federal bureaucracy).

Figure 1 is an outline of the complex relationship of the hospital to the Health and Hospitals Corporation, the City of New York, and affiliated Mount Sinai School of Medicine. For this project, the capital appropriation came directly from New York City Board of Estimates. Funds for construction and changes in telephones had to be obtained from Health and Hospitals Corporation. The City administration

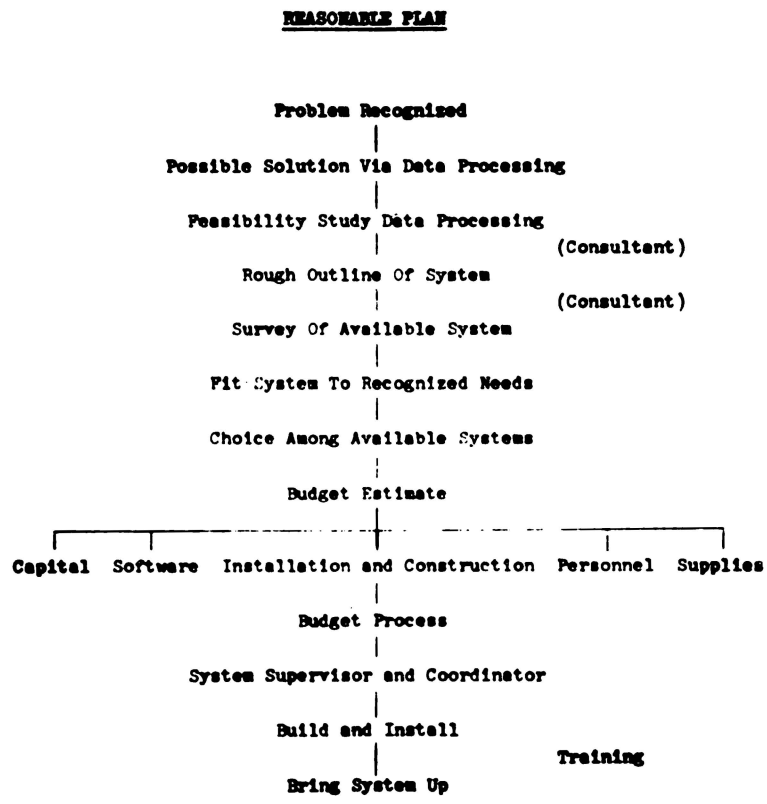


Figure 2

at Elmhurst had to supply clerical personnel, furniture and supplies. Supervisory personnel comes from the Mount Sinai affiliation. Nobody has all the strings.

A logical approach to the creation and acquisition for a radiology management data processing system might be illustrated by Figure 2. There is reasonably orderly progression from recognition of the problem to inauguration of system.

WHAT ACTUALLY HAPPENED

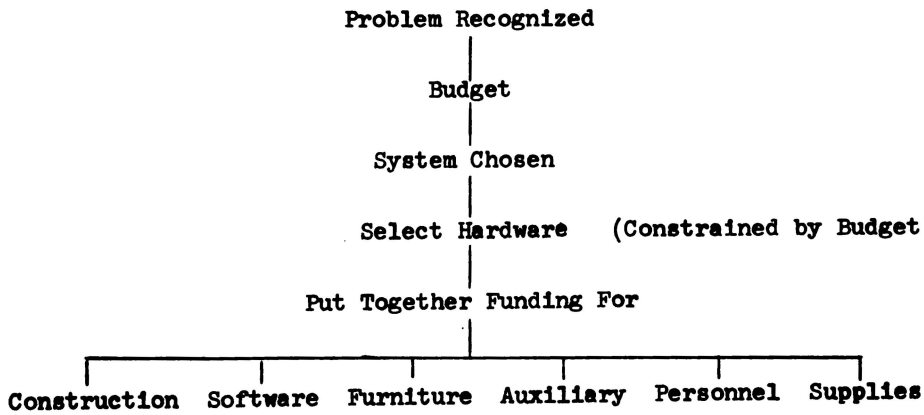


Figure 3

Our approach (Fig. 3) defies analysis and flies in the face of every lecture, treatise, and tract on data processing systems. All of us realized the danger of the approach, but the alternative was nothing.

The Department of Radiology at Elmhurst had no expertise in data processing, and no access to consultants. We approached National Computer Systems which had, in July 1980, the only operational system that seemed applicable. Figure 4 shows the major problems and their proposed solutions.

Unfortunately, there is no solution to the illegal alien

PROBLEMS	SUGGESTED SOLUTION
1. Statistics unable to support budget request.	Entry of study into system prior to execution. Develop own data base.
* * * * * * * * * *	* * * * * * * * * *
2. Film loss due to:	
a) Theft by house staff.	a) Use of optical bar-code to identify: House staff Patient Examination
b) Felony theft for silver.	
c) Duplication of folders.	
d) Duplicate name.	b) Secure darkroom and file area so all film transfers are recorded.
e) Non-return of films.	
f) Clerical staff demoralization.	c) Use data base to eliminate duplications.
* * * * * * * * * *	* * * * * * * * * *
3. Film reporting.	Parallel systems.
a) Inaccurate transcribed reports and late reports.	a) Dictate - Word Processor Memory - 30 days
b) Lost reports.	b) Canned normals (Bar-code) Memory - 30 days
c) Delay in reaching charts.	c) Mark sense forms Memory - 30 days
* * * * * * * * * *	* * * * * * * * * *
4. No teaching file	Ten (10) digit ACR type case file.
* * * * * * * * * *	* * * * * * * * * *
5. Billing	Not relevant internally, tape-to-tape transfer of data to hospital computer.
* * * * * * * * * *	* * * * * * * * * *

Figure 4

problem. The use of aliases, borrowed medicaid cards and forged identifications leaves a significant number of cases that cannot be identified.

The System looks like this (Fig. 5). We use a PDP - 11/34 and a CDC 9766 Disc Drive with 300 megabyte storage. It is distributed over three hospital floors, and is entirely hardwired. The modem is used only to communicate with the

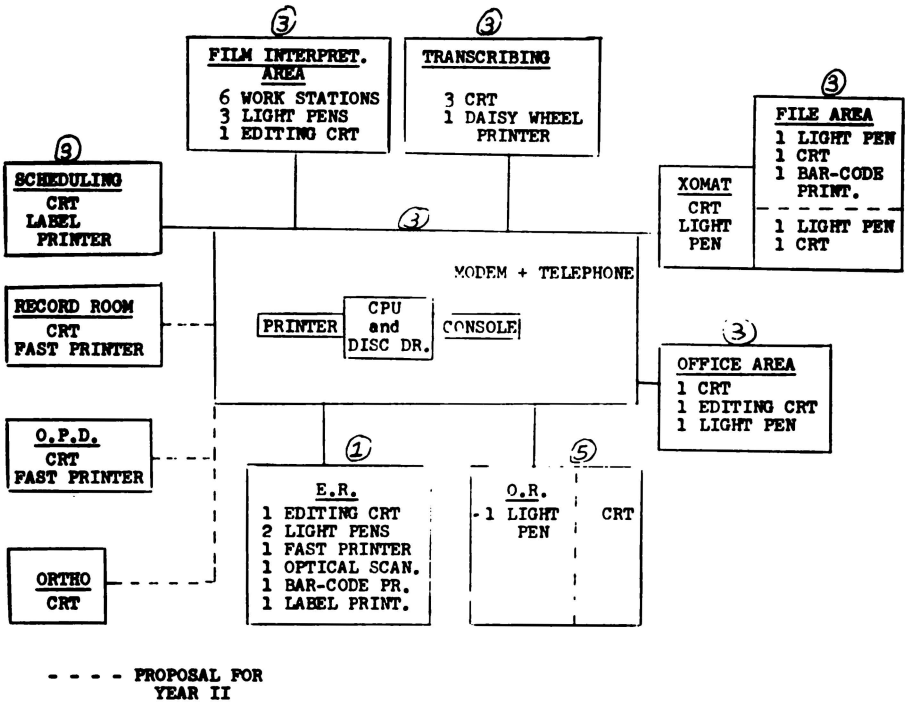


Figure 5

vendor's service organization. Dotted lines are terminals proposed for year two.

A data processing system requires the interaction of hardware, software and management in order to function. Deficiency in any one component can limit the system severely. Out enviornment is still under construction and the system functions far below its design capacity at this time.

HARDWARE

Hardware problems have been almost non-existent. Elmhurst has not been kind to its system. Temperature of the CPU has wandered from 40-95°. The enviornmental temperature at some work stations has been over 110°. Continued construction has scattered plaster and cement over the entire department. The fact that we have had no major breakdown is a tribute to the designers of the CPU and disc drive, and to the NCS service crew.

We found that a daisy-wheel printer produced a more acceptable and less ambiguous x-ray report than a matrix printer.

I also believe that greater attention must be paid by manufacturers and vendors to the problem of the presbyopic radiologists and clerks.

We have had no theft of components and no tampering with terminals overnight. This was, frankly, a surprise.

SOFTWARE

Our software functions at specified levels but there are certain things that our system does not do that seem to be within the capability of the hardware.

Maxifile III does not sort or categorize very well. Our reporting system can print interpretations sorted by radiologist, ward or referring physician.

a) The file management system will not generate a working list arranged by terminal digit for the clerks to use when pulling films for clinics.

b) It will not list by date films borrowed but not returned.

c) It will not list, by service, films borrowed but not returned.

d) Interesting cases can be recalled only by a single ACR code. Additional information entered cannot be used to sort interesting

cases by age, multipicity of diagnoses, or any other criterion.

e) Our signed and approved reports are not quite tamper-proof. A report stored in memory can be changed even though a printed and signed report has been issued. This may create medico-legal problems in the future.

f) The date on the computer printed report is the date of print-out. There is no indication of the transcription date, the date of radiologist's approval or that the report may be a duplicate.

g) The label code is too cryptic and there is no earthly reason to require a clinician to learn the code.

Software modification is under discussion.

There are several functions that I would prefer to function automatically, but do not.

a) The system does not automatically withdraw recognition of film borrower when films are not returned. The detection of the default can be made only by inquiring about the location of a specific folder or the default of a specific borrower.

b) The light pen system allows the wrong examination to be reported, i.e., a foot can be reported as a normal chest even though the input sequence re-registers the nature of the examination being reports.

There is one problem that may or may not be amenable to software modification but seems to impede a smooth and logical operation of the system.

A CRT will not accept command from an

adjacent light pen. The light pen is a rapid method which ought to be utilized to input complex commands which are repeated frequently. I see no reason to punch in the patient's number and an inquiry on prior reports if the patient's folder, bar-codes and a light pen are at hand.

RESIDENT ACCEPTANCE

Raport II has a manual about as thick as a standard text in medical physics. Residents in our training program, spending twenty per-cent (20%) of their time in this institution simply will not put forth the required effort necessary to learn a system which has limited application.

MANAGEMENT

Red tape, divided authority, and poor coordination

combined to prevent the operation of our system at specified levels. I cannot emphasize too strongly the need for a single czar or manager for the installation of a data processing system. Unless one individual has complete power and authority over the construction, installation, purchase of supplies, personnel, and training; the impact will be lost and morale will tumble. Lack of coordination and delayed construction has wrecked our training schedule and is forcing us to bring the system up piecemeal. Our x-ray file area has had no doors for the past four weeks, and our data base is vanishing with the films.

SUMMARY

Our infrastructure is in place and our data processing system functions. Our progress toward full operation has been slow. I hope that the rather unusual conditions imposed on Elmhurst have highlighted potential problems and

point the way toward more comfortable transition for other hospital departments.

A CODE ORIENTED RADIOLOGY REPORT SYSTEM

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INTRODUCTION

The purpose of this paper is to describe the Radiology Reporting System which is based at LDS Hospital in Salt Lake City, Utah. LDS Hospital is a 520 bed hospital and the annual volume in the Radiology Department is approximately 75,000 examinations per year. The LDS Hospital Radiology system is not a stand alone system, but an integral part of a hospital-wide clinical system for medical decision-making known as HELP. The data base and decision-making system runs on a network of 6 Tandem computers. There are 250 CRT terminals connected to the system. These terminals are available at each nursing division in the hospital as well as in some physicians' offices. The goal of the radiology reporting system is to capture salient, clinically pertinent radiology findings for use in this comprehensive computerized clinical data base. In designing the system, we settled upon two major constraints which had to be satisfied. The first constraint was that the radiological findings be coded for storage in the computer so that findings could be retrieved, analyzed, and used for medical decision-making as well as physician review. The second contraint was that the system must be unobtrusive to radiologists so that they would cooperate in entering findings into the computer. To meet both of these requirements we decided to let the radiologists report pertinent clinical findings by selecting from an individualized list of likely findings for each patient. The most important information in a large majority of Xray examinations can be reported with a limited list of possible findings. The finding of normal chest could be used to report 14% of all Xray procedures at LDS Hospital. By using the twenty-two additional most common findings, it is possible to report the salient findings in 80% of all procedures. Even in

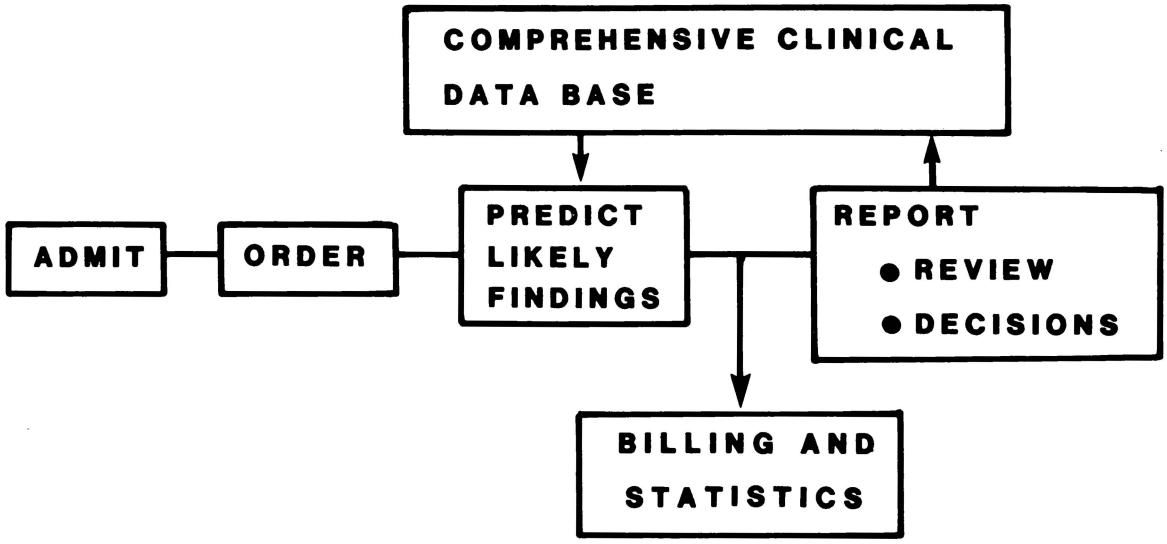


Figure 1. A block diagram of the computerized radiology reporting system which has been developed as an integral part of the HELP system for medical decision-making.

the specialized area of chest exams which has a wide variety of abnormal pathology, the 15 most common findings can be used to report 90% of the examinations. For an individual patient for whom a specific procedure has been ordered is possible to further narrow down this list to the five most likely findings by using patient specific data. Computer based medical logic is used to make this list appropriate for each patient.

SYSTEM DESCRIPTION

Based upon this philosophy, our system was designed using the modules shown in the block diagram in Figure 1. In this figure the box labeled "additional clinical data" really represents the other 90% of the HELP system. This data base contains computer-generated ECG interpretations, all clinical laboratory results, all in-hospital medications, allergy history, surgical

procedures, pulmonary function test results, blood gas analysis and monitoring information and vital signs for intensive care patients.

The next module of the system is the admit function. The admit program is based upon the existence of two computerized files: a long-term file which contains birthday, address, insurance information, the date of the last Xray examination, previous discharge diagnoses, and other abstracted clinical information from previous visits to the hospital.

The key to storage in this long-term file is the permanent radiology file number. This radiology file number is constructed using a hashing algorithm which depends on the patient's name and sex and the day of the year the patient was born. A patient who returns to the Radiology Department will receive exactly the same file identification number which was calculated the first time if the name and birthday are correct. An alternate key to the long term file is based upon soundex coding of the name. If there is any emergency admission in which only part of the information about a patient is known, it is possible to go to the long-term file, look at the names and addresses of possible matches for the patient who is being admitted to the hospital, and select which, if any, of the previous long-term file entries is appropriate for that patient.

As a patient is admitted to the hospital, an entry in a short-term file is also created to store detailed clinical information regarding the present visit. Patients may be admitted at any of several locations throughout the hospital, including the Xray Department, and the computer admission satisfies the hospital financial system requirements. The Xray ordering program asks

for the patient name, ordering clerk, requesting physician, mode of transportation, and any special handling requirements. Up to five previous Xray procedures ordered for that patient are displayed in order to help reduce duplicate or unnecessary examinations. The next step in the program depends whether the order is being generated from the nursing divisions of the hospital or by personnel in the Radiology Department. When the examination is ordered in the Radiology Department, a specific procedure and clinical reason for performing the examination, are obtained by displaying frames of multiple choice menus. The menus link textual choices with codes which are to be stored in the computer. A clerk must normally select entries from four different frames to specify a procedure and the clinical reason for the examination. From experience, we found that personnel on the nursing divisions did not have sufficient background to properly specify the appropriate radiological examination. For example, should a physician's request for an "abdomen" be a single view flat plate or the standard 3 view series? For this reason, the ward clerks at the nursing divisions do initiate the order for an examination, but they enter free text from the physician's requisition. The radiology personnel are signalled that an order is pending, and they interpret and specify the appropriate procedure and clinical reason for examination. In exceptional instances free text may be entered to describe unusual procedures or reasons for ordering the examination. After the ordering process is completed, the paper work necessary to perform the examination is printed. This packet consists of: 1) a film label, (flash card); 2) a peel-off strip which is used as the film folder label (this label contains a bar-code so that the film jacket may be tracked); 3) an orderly pickup slip which lists special transportation and handling requirements, and 4) a technician

DEPARTMENT OF RADIOLOGY 4S 6 12 1950 LDS HOSPITAL
Phone (801) 350-1791 325 Eighth Ave Salt Lake City, Utah 84143

Patient: SUSAN NMI Age: 31F CHEST 1 10
Room: 4S30 Date To Be Done: 21 APR 82 PNEUMONIA
Hospital # 2828762 Radiology # 66-96-864
Requesting Physician: Mc MaHILL, PHILIP
Attending Physician: LARKIN, RON
Computer Entry: 20 APR 82 By: SPX
Admitting Diagnosis: POST PARTUM COMPLICATIONS

Radiology Report Summary **

CHEST 1		Initial Finding	No Change	Increased	Decreased	Mild Few Small	Moderate Several Medium	Severe Many Large	Definite	Probable	Possible	Indefinite
NO SIGNIFICANT ABNORMALITIES	A	1	2	3	4	5	6	7	8	9	10	11
HYPOAERATION/ATELECTASIS L/R	B	1	2	3	4	5	6	7	8	9	10	11
INFILTRATE/PNEUMONIA	C	1	2	3	4	5	6	7	8	9	10	11
PLEURAL EFFUSION L/R	D	1	2	3	4	5	6	7	8	9	10	11
RESPIRATORY DISTRESS SYND	E	1	2	3	4	5	6	7	8	9	10	11
PULMONARY EDEMA	F	1	2	3	4	5	6	7	8	9	10	11
OTHER	G	1	2	3	4	5	6	7	8	9	10	11
	H	1	2	3	4	5	6	7	8	9	10	11
	I	1	2	3	4	5	6	7	8	9	10	11
	J	1	2	3	4	5	6	7	8	9	10	11
	K	1	2	3	4	5	6	7	8	9	10	11
	L	1	2	3	4	5	6	7	8	9	10	11
	M	1	2	3	4	5	6	7	8	9	10	11

** The conditions printed above are simply computer calculated possibilities determined prior to the examination. They represent radiologic interpretations ONLY if their corresponding boxes are checked. See text below for detailed report.

Figure 2. A copy of the requisition/report form generated when a single view portable chest film was ordered to rule out pneumonia in a patient suffering post partum complications. The list of likely diagnosis is patient specific.

confirmation slip, which also has a bar-code label on it. When technicians finish an examination, they confirm that the exam was actually performed as ordered using a bar-code reader. If the examination was altered they write a note on the slip which lists any changes in the ordered procedure, and office personnel reconcile the computer entry.

The second form generated at the time the examination is ordered is the requisition/report form, which contains the individualized list of most likely findings for that procedure (see Figure 2). In this case a 31 year old female patient was admitted to the hospital because of post partum complications and a portable single view chest radiograph was ordered to rule out pneumonia. The most likely findings were: no significant abnormalities, hypoaeration, infiltrate, pleural fluid, respiratory distress syndrome, and

pulmonary edema. The generation of this patient specific list of likely findings is the most unique aspect of our radiology system. In order to predict the most likely findings, we have written medical logic for 378 different types of findings. Whenever any type of chest examination is ordered, logic sectors for each of the 45 most frequent chest findings are evaluated and the five sectors with the highest likelihood are printed on the requisition/report form. The logic in these sectors is based upon indicants which are found to be significantly correlated to a specific finding.(1) Such indicants include age, sex, and other clinical data in the computer. The most important indicant is usually the physician's reason for ordering the examination.

The actual use of these indicants to predict the presence of a specific finding is based upon sequential applications of Bayes' formula. Bayes' formula states that the adjusted probability of a finding given the presence of a certain indicant $P(F|I)$ is equal to the probability $P(F)$ of that finding before anything is known about the presence or absence of the indicant multiplied by a ratio. This ratio is the probability that the indicant will be present in patients with the finding $P(I|F)$ divided by the probability that the indicant will be present in the general population. The denominator of this formula just calculates the probability of the indicant, for those with, $P(I|F) \cdot P(F)$, and without, $P(I|\overline{F}) \cdot P(\overline{F})$, the finding. This formula may be written: $\frac{P(F)\ P(I|F)}{P(F)\ P(I|F)+(1-P(F)) \cdot P(I|\overline{F})}$. To calculate the effect that specification of chest pain as the reason for ordering a chest examination has upon the likelihood of finding pleural fluid, we analyzed the data base to obtain certain conditional probabilities. We found that the probability of chest

pain being given as the ordering reason for patients who subsequently had pleural fluid was 2.2%. The probability of chest pain as the ordering reason for patients who did not have pleural fluid was 7%. The a priori probability of pleural fluid by chest exam if nothing else is known about the patient is 15%. The revised probability of pleural fluid because chest pain was given as a reason for ordering the exam is only 5%, or a drop of 10%. In a similar fashion, the other independent indicants may cause the probability of pleural fluid to increase or decrease. After the logic for all 45 common chest findings is evaluated in such a manner, it is possible to predict the most likely findings for the requisition/report form. This form goes to the radiologist's office where the film is read and the appropriate boxes are checked. Traditional detailed dictation is typed by a secretary on the bottom of the sheet, and the selected findings are entered into the computer by the secretary. Once the information is entered into the computer, it is available for review at all nursing stations, as well as other terminal locations. This mode of data review is used to ascertain lab results and medications, as well as Xray findings, and is readily used by nurses and physicians to review the patient's status.

The final module of our systems concerns billing and management statistics. Every morning a secretary goes over the list of examinations which were done the previous day listed by the sequence number in which they were ordered. At the time of order, each procedure is entered into a transaction log. If the technician performed a bar-code confirmation, the examinations are not presented to the secretary by the computer. After the secretary makes necessary changes to the unreconciled log entries, the program sets the "ready to

bill" bit on the entries for that day. Radiologist and hospital charges, as well as ICD9 codes for use by insurance companies, are defined for each procedure and the transaction string contains space for additional charges. After the hospital financial system has received these charges, a "billed" bit and date are set in the transaction entry for each procedure. For the radiologists, who are a private practice group located in the hospital, we provide a print-out/tape of the Xray transaction log and necessary demographic information. We generate daily, bi-monthly, monthly, and yearly statistical logs which list the quantities of each type of examination which were performed during the appropriate time period.

RESULTS

We presently have 794 coded examinations, 435 reasons for performing the examinations, and 378 coded findings. Sixty-four percent of all examination results are completely coded and entered into the computer. Currently the disposition of eight percent of the examinations is not being entered into the computer. The 12 private practice radiologists is the hospital choose not to check boxes when reporting eight percent of the examinations. Success in correctly predicting all pertinent clinical findings ranges from 84% for skeletal examinations to 12% for angiographic procedures. We correctly predict all of the likely findings for 65% of the chest examinations. In twenty percent of the chest examinations we failed to have any of the reported findings on our predicted list.

DISCUSSION

From our initial experience with this report system, we have accumulated

a sufficiently large coded data base to allow us to ascertain which clinical indicants provide significant predictive information. Because we have not yet developed sophisticated logic for predicting the majority of the findings, we expect that our ability to correctly predict the most likely diagnosis will continue to improve. Improved ability to predict likely findings will be of interest, not only for our reporting scheme, but also to those desiring to address the issues of efficacy and utility.

The longstanding problem of providing an acceptable interface between the computer and the professional clinician is one of the major impediments to realization of the potential of computer applications. This potential includes an enhanced ability for performing clinical research which assesses the efficacy of radiological examinations, and the even more exciting capability of providing computer assistance to the medical decision-maker. To achieve these goals the medical information system of the future will undoubtedly rely upon some form of coded radiological findings which are integrated into a comprehensive clinical data base.

The long term benefits of computer applications in medicine will come when the computer can substantially expand the capabilities of an individual physician. It is generally recognized that such enhancement will come as we are able to encode an expert knowledge base into the computer which will act upon the clinical data base in appropriate instances. It is with this goal in mind that we have tried to develop a simple way in which the radiologist can conveniently enter clinically relevant information into the computer. As the advantages of expert based consultation systems become evident and new

technology evolves, we expect that many of the present interface difficulties will be resolved.

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CLIP: A 1982 UPDATE

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Many radiologists still believe that computerized on-line reporting offers no real advantages which could not be achieved more easily by making conventional dictation methods more efficient. If dictabelts were simply collected and transcribed more quickly, reports returned for signature more frequently, and the approved reports delivered promptly to the floors and hospital departments, the need for computerized reporting would not exist.

The fallacy of this argument became evident in a recent experience at an overseas hospital. The reporting rooms in this hospital's Department of Radiology were on each side of the transcriptionists' room. Dictation belts were exchanged and typed reports were returned frequently. The manual delivery of reports was efficient by any standards. Nevertheless, most outpatients actually carried their unreported films from the Radiology Department to their clinics. The clinicians would not wait even a few hours for the radiologists' reports and preferred to interpret the x-ray studies on their own. The reports on these cases were typed and delivered to clinics the following day. It is obvious that under such circumstances, the radiologist's skills and knowledge are not being effectively utilized. In fact, his report as such is largely irrelevant in terms of case management.

The flaw in the traditionalist argument is rather obvious from this

anecdote. Similar experiences are common in most radiology departments. Even if the radiologist's report reached its destination only hours after the films were taken, it would usually be too late. In truth the only wholly satisfactory system would be one in which each study is interpreted and the results made available before the patient is seen in the ward or clinic.

What is the extent of change in reporting methods the radiologist must accept to accomplish meaningful reporting rather than personal convenience? The leisurely use of dictating machines, later signing of reports when a convenient moment approaches, and condignly tolerating batch delivery of reports hours or even days later, must be recognized as unacceptable. Unless radiologists are willing to embrace the necessary changes in their reporting habits, the contribution of their reports in patient management will be severely restricted because of their untimely arrival. I wish to describe our efforts to address the reporting problem at the Beth Israel Hospital in Boston.

CLIP (Coded Language Information Processing) is part of a hospital-wide computerized clinical information system which is operated through 6 Data General C-330 computers. It is designed to make reports immediately available and to provide longterm access to these reports for statistical and scientific medical analysis. Television terminals with keyboards are used for inputting and viewing information, although two years ago we experimented briefly

with a system in which microphones were used in place of keyboards for data inputting (1).

The upper part of the television screen displays the patient's demographic data. Below this, the narrative report prints as it is compiled, while in the bottom third, the menus of appropriate statements are displayed to assist the radiologist in assembling his report. The system is based on a coded radiologic classification, the Simon/Leeming classification (S/L), which has been extensively expanded since its development in 1970-71. It is designed to encode not only the actual or presumptive diagnoses, but also the radiologic observations leading to the diagnosis, which have considerable scientific potential. This classification has been described many times (2,3,4). It is heirarchical in form, and is coded alphanumerically. The classification has "Anatomy", "Findings", and "Etiology" sections, and items from each may be combined to provide diagnoses.

Originally, the reporting technique required the radiologist to assemble the words of his report from the S/L code, assisted by the computer. In practice this was far too slow and cumbersome. However, experience with this item-by-item technique led to an important concept in which not words but whole ideas or themes were preassembled in code and made available to the radiologist. The radiologist locates and enters the appropriate themes from the menus displayed on the terminal. Having entered the themes, the

computer converts these into sentences and phrases with appropriate pauses for the radiologist to select words from lists of computer displays such as mild, moderate, and severe, or small, moderately large, large, or other relevant modifiers.

This version of CLIP was successfully implemented in our department and the preassembled statements were expanded over time into a very large, comprehensive collection. Such development required increasingly complex rules of computer operation so that the processing of reports became progressively slower to an unacceptable degree. This became enough of a problem that in 1979 a decision was made to abandon word-by-word translation of coded data into narrative, hitherto the essential feature of CLIP, and thenceforth, the statements were written directly into narrative. However, the objective of data retrieval was not forgotten. At present, new CLIP statements exist only in narrative form, but in the near future the S/L code equivalents will be secondarily written in succinct form parallel to the narrative form, the two being stored together. The reports will then be generated on-line directly in narrative, as at present, to provide the necessary speed for the reporting process. At a later time when the cases are no longer active, the narratives will be replaced by the coded versions and only these will be retained. These coded reports will be held indefinitely and thus, can be analyzed scientifically at any time. If any report should later be required again for clinical purposes, it can be regenerated from code into narrative,

which will merely be a literal translation of the coded abstract, rather than the recreation of the original narrative version. By eliminating the item-by-item conversion from code to narrative, a much faster operation for the computer and also the radiologist has resulted. Additionally, the process of entering and hierarchically organizing a vast array of required statements into the lexicon has been simplified.

At present, somewhat over 60% of all our reports are directly entered into the computer. For about 18 months this figure has been static, but now that a large part of the rewriting into new CLIP has been completed, the percentage of directly entered reports is beginning to rise as new areas such as ultrasound and computerized tomography become available.

The residual 30% of reports which are still dictated are text edited by a transcriber directly into the computer. The radiologist reviews and approves these reports, also on a terminal. Once approved, usually 4 to 48 hours later, they are printed and delivered to the nursing stations and referring physicians for entry into the patient record. The interim unchecked report, prior to being approved, may be studied on any hospital terminal just as are the directly entered and approved radiology reports, and all other computerized patient data from other departments such as hematology, bacteriology, and biochemistry.

Whereas the preassembled statements in the old CLIP system were generally highly organized heirarchical displays, the new CLIP preassembled themes are more freely organized into information frames which are essentially independent in nature, but which interconnect when necessary by having any selected item from a frame "point" to other frames of related information.

It is not the purpose of this presentation to review earlier versions of CLIP in any detail. However, some reference must be made to the previous version (old CLIP) to help explain the operation of the newer version (new CLIP).

Old CLIP was programmed so that for any one display of options no more than nine items could be presented. This frequently meant that the user had to select successive options from subordinate frames of data before locating the needed statement. Since New CLIP permits 35 items on the screen, the selection process usually locates the wanted item with far fewer changes of display.

In Old CLIP the finding of a wanted statement did not necessarily mean that the radiologist knew how the full statement would ultimately appear in narrative form because the selection from abbreviated lists was followed by a processing delay before translation. Thus, he might later have to delete the statement since it did not adequately reflect his opinion. This problem is minimized with New CLIP since the complete narrative is immediately visible.

EXAM FAMILIES

H	HEAD & NECK	G	GYN & OBSTET
S	SPINE	U	UPPER LIMBS
C	CHEST	L	LOWER LIMBS
M	MAMMOGRAPHY	N	NUCLEAR
A	ABDOMEN	E	ECHO
D	DIGESTIVE	V	VASCULAR
B	BILIARY	F	FINDINGS
R	RENAL	T	TISSUES
P	PELVIS		

FIGURE 1

In Old CLIP, any selected preassembled statement could be loaded with optional inserts to maximize the freedom of the user to select from a wide range of variations. This had the effect of greatly increasing the range of applicability of the theme embraced in the statement to many slightly different situations. Whilst this is beneficial, it required increased complexity. On the other hand, New CLIP, by displaying up to 35 options per frame, allows any option to be inserted into the report, or, if not applicable, simply ignored.

New CLIP frames, although essentially independent of each other, are in practice, clustered together in seventeen families (Figure 1).

THE ANKLE

1. NORMAL	A. DEGEN. JT. DIS.	J. VASC. CALC'N
2. NO FRAC. OR ??FRAC.	B. CHONDROCALCINOSIS	K. STS/EFFUSION
3. TRAUMA	C. DIFF. DIAG. ABOVE	L. FRAC. BODY
4. FRACTURE FOLLOWUP	D. OSTEOCHOND. DISS.	
5. LUCENT/DENSE AREAS	E. ARTHRODESIS	
6. OSTEOMYELITIS		
		P. POOR STUDY
		Q. UPDATE
		R. FILL INS

FIGURE 2

For each family, a master frame has been constructed which displays a range of options intended to cover all the likely normal or abnormal findings and observations (Figure 2). In some of the families such as upper and lower limb, the range of possible options is much smaller than in other families such as ultrasound or CT head scans. The number of options, and consequently the number of frames, may differ greatly from family to family.

At present, more than 6,000 frames have been composed and stored in the computer memory. Many families of frames, particularly those represented by head and neck, chest, abdomen, the genitourinary system, the extremities, and ultrasound, are sufficiently complete so that they are in routine use and require only occasional editing

changes. Our estimate is that ultimately the number of frames will probably increase to about 12,000.

The emphasis in this presentation has been on the use of CLIP for the speedy generation and delivery of x-ray reports. However, it also offers many other advantages to the user. It is part of a comprehensive computerized department operation which facilitates patient billing, monitors the day to day activities of the department, and provides valuable managerial statistical data important for planning and development, and for estimating future needs.

The radiologist user also enjoys many other advantages besides rapid reporting. He or she is able to enter selections from well researched lists of differential diagnoses placed at many strategic points. The key features of many syndromes are displayed for perusal when necessary and recommended further tests or studies are listed as required and are easily incorporated into reports.

The hospital-wide computer system offers other benefits. Not only radiology, but also biochemistry, bacteriology and other reports on any patient are easily accessible on the computer terminal. There is an electronic mail system for sending and receiving messages. Literature searches with printouts are easily performed. Every user has access to a built in calculator which performs a range of statistical and other computations. This list by no means exhausts the range of advantages enjoyed by users.

METHOD OF USE

When a patient reports to the Department of Radiology, a receptionist enters appropriate demographic information including the name of the requested study using a simple examination code. The computer assigns an accession number. Once the examination is completed and the films are sent for reporting, the radiologist enters the accession number on his keyboard. The patient's name, age, hospital number, and other relevant data are displayed. In the bottom part of the screen the master frame of statements for the particular study appears. The radiologist having first decided what is to be reported, selects the appropriate statements, or those of dependent subframes, and finally, after editing the report if necessary, approves it. At this point the report is immediately available to every authorized user in the hospital on any of the 250 terminals situated on various floors and in most departments.

Two examples of the method of use will be shown, both related to ankle studies.

Example 1

A routine ankle series was requested because of recurrent pain in the ankle, no cause known. The ankle appeared radiologically normal.

The radiologist selects item 1 from the master frame display (Figure 2). Note the frame layout with "Normal" as item 1, bone

NORMAL ANKLE

1. NORMAL (GEN)	A. NO JOINT ABN.	J. NO S.TIS.ABN.
2. NO BONY ABN.	B. NO D.J.D.	K. NO TENDINITIS
3. NO FRACTURE		L. NO FRAC. BODY
4. NO METS		
5. NO OSTEOMYELITIS		
		P. POOR STUDY
		Q. UPDATE
		R. FILL INS

FIGURE 3

findings in the left column, joints in the middle column and soft tissues on the right.

The selection of item 1 causes the frame of "Normals" to appear (Figure 3) and this is also laid out in columns for bones, joints and soft tissues. Items 1 and B are selected.

The resulting report reads "No bone, joint or soft tissue abnormality is seen. There is no evidence of degenerative joint disease."

Example 2

A 20 year old football player sustained an injury to his right ankle and was unable to bear weight on it. An eversion type fracture dislocation is identified.

THE ANKLE

1. NORMAL	A. DEGEN. JT. DIS.	J. VASC CALC'N
2. NO FRAC. OR ??FRAC.	B. CHONDROCALCINOSIS	K. STS/EFFUSION
3. TRAUMA	C. DIFF. DIAG. ABOVE	L. FRAC. BODY
4. FRACTURE FOLLOWUP	D. OSTEOCHOND. DISS.	
5. LUCENT/DENSE AREAS	E. ARTHRODESIS	
6. OSTEOMYELITIS		
		P. POOR STUDY
		Q. UPDATE
		R. FILL INS

FIGURE 4

FRACTURES AND DISLOCATIONS (ANKLE)

1. FRACTURE NO DISLOCATION
2. FRACTURE/DISLOCATION
3. EPIPHYSEAL TRAUMA

FIGURE 5

The radiologist selects item 3 from the ankle region master frame (Figure 4). The new frame displayed (Figure 5) contains only three items.

Selection, in this case item 2, eliminates non-relevant options from future selections. The next frame is displayed (Figure 6). The printout of item 2 stops for the selection of the side of injury (which may be omitted) (Figure 7).

FRACTURE/DISLOCATION (ANKLE)

1. NO FRAC.OR DISLOC.	A. TRANSV.FR.M.MAL.(ADD)	J. M.DISPL.TALUS
2. FRACTURE DISLOC.	B. VERT.FR.M.MAL.(ADD)	K. L.DISPL.TALUS
3. EVERSION FRAC./DIS.	C. FR.TIP M.MAL.(ADD)	L. A.DISPL.TALUS
4. INVERS.FRAC./DISL.		M. P.DISPL.TALUS
5. DISL.INF. T/F JT.	E. TRANSV.FR.L.MAL.(ADD)	N. STS/EFFUSION
6. COMPRES.FR.TIB.	F. SPIRAL FR.L.MAL.(ADD)	O. FIXED BY
	G. FR.TIP L.MAL. (ADD)	P. POST OP. POS'N
		Q. FRACTURE F/U
9. WITH (ADD)	I. FR. POST. MAL. (ADD)	R. UPDATE

FIGURE 6

THERE IS A FRACTURE-DISLOCATION OF THE

1. LEFT
2. RIGHT
3. LEFT AND RIGHT

FIGURE 7

The report at this point reads "There is a fracture dislocation of the right ankle." Further details are now entered as shown (Figure 8).

The final report reads "There is a fracture dislocation of the right ankle with a transverse fracture of the medial malleolus and a spiral fracture of the lateral malleolus with moderate lateral

FRACTURE/DISLOCATION (ANKLE)

1. NO FRAC.OR DISLOC.	A. TRANSV.FR.M.MAL.(ADD)	J. M.DISPL.TALUS
2. FRACTURE DISLOC.	B. VERT.FR.M.MAL.(ADD)	K. L.DISPL.TALUS
3. EVERSION.FRAC./DIS.	C. FR.TIP M.MAL.(ADD)	L. A.DISPL.TALUS
4. INVERS.FRAC./DIS.		M. P.DISPL.TALUS
5. DISL.INF. T/F JT.	E. TRANSV.FR.L.MAL.(ADD)	N. STS/EFFUSION
6. COMPRES.FR.TIB.	F. SPIRAL FR.L.MAL.(ADD)	O. FIXED BY
	G. FR.TIP L.MAL. (ADD)	P. POST OP. POS'N
		Q. FRACTURE F/U
9. WITH (ADD)	I. FR. POST. MAL. (ADD)	R. UPDATE

FIGURE 8

displacement of the talus." The radiologist may select other items from the master frame if necessary (Figure 9).

The final report is a model of brevity and order written in proper English, yet its compilation did not involve any complex decision making. If an observation is required which is not among the displayed options it can be entered as free text at any place in the report.

We have now had 10 years of experience with computerized reporting and have modified and improved the basic method of direct entry of preassembled items so that today the technique is effective and simple to use. Whilst further development is required there is no longer any reason to doubt that CLIP will survive. It offers a

FRACTURE/DISLOCATION (ANKLE)

1. NO FRAC.OR DISLOC.	A. TRANSV.FR.M.MAL.(ADD)	J. M.DISPL.TALUS
2. FRACTURE DISLOC.	B. VERT.FR.M.MAL.(ADD)	K. L.DISPL.TALUS
3. EVERSION.FRAC./DIS.	C. FR.TIP M.MAL.(ADD)	L. A.DISPL.TALUS
4. INVERS.FRAC./DIS.		M. P.DISPL.TALUS
5. DISL.INF. T/F JT.	E. TRANSV.FR.L.MAL.(ADD)	N. STS/EFFUSION
6. COMPRES.FR.TIB.	F. SPIRAL FR.L.MAL.(ADD)	O. FIXED BY
	G. FR.TIP L.MAL. (ADD)	P. POST OP.POS'N
		Q. FRACTURE F/U
9. WITH (ADD)	I. FR. POST. MAL. (ADD)	R. UPDATE

FIGURE 9

valid solution to the urgent problem of instant availability of medical data to clinicians even when this data is complex by nature as in radiologic reports.

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RADIOLOGY FILM RECORD COMPUTER RETRIEVAL SYSTEM

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INTRODUCTION

The film record information system is the functional hub of the radiology department. Most radiology departments use a manual card file system for film records. Unfortunately, this card catalog is outdated, inefficient, and highly error prone, limiting the quality of services provided to both patient and physician. By general concensus, up to 30% of all records in a manual X-ray card catalog are misfiled, duplicated, incorrect, or lost.

National Medical's Radiology Film Retrieval System, RFR, has been designed specifically for use in radiology departments and provides workable solutions to the inherent problems of the manual film record system. RFR allows X-ray records to be cataloged and retrieved by patient name or by X-ray number and eliminates the patient card file. RFR operates on Data General computers.

EASE OF OPERATION

The RFR system is simple to operate and designed for use by radiology department clerical personnel.

All program functions are conveniently selected from one of two menus

by simply entering the number preceeding the function description. All RFR programs have been designed to clearly prompt the operator for required responses. Interactive editing insures reasonable and valid input data. Additionally, RFR includes a program supervisor which controls sequence dependent functions and prevents concurrent execution of mutually conflicting menu selections.

AUTOMATED RECORD RETRIEVAL

With a manual card file, patient film records are easily lost through misfiling. With RFR, record misfiling is impossible. The computer automatically files each patient record into the correct name and X-ray number sequence during record creation. Retrieval of patient records is automatically accomplished via a data management program. The operator simply enters a patient name or current X-ray number and, instantly, all records starting at the specified name or X-ray number are displayed in ascending alphabetic or numeric order, respectively.

The fields displayed on initial inquiry include X-ray number, patient name, birthdate, sex, and race. The information display allows the operator to determine, at a glance, whether or not a film record for the patient already exists. With RFR no patient's film record can be misfiled and "lost" within the system, as so commonly occurs with a manual card file system. The RFR inquiry function also minimizes the possibility of assignment of multiple X-ray numbers to one patient.

The operator can cause the inquiry screen to roll forward from the initial reference point to display the next set of names in sequential order. This feature is particularly useful when searching for a specific "Smith", when there may be dozens on the system. Any patient record displayed can be selected for addition of new film studies or modification of existing data merely by keying the reference number preceeding the patient's name. If the inquiry scan screen reveals no existing film record for the patient, the operator merely strikes the appropriate function key and a "NEW PATIENT" screen comes up to prompt for entry of necessary data. In contrast to a manual card file system, it is impossible to assign the same X-ray number to more than one patient on the RFR system.

Each RFR patient record is composed of two parts:

- Patient information: current X-ray number, patient name, date of birth, sex, race, hospital number, and emergency room number.

- Film information: X-ray number, film date, patient type (in, out, or emergency), procedure, referring physician, diagnosis, and film location. RFR retains all patient film information since record inception.

With a manual card system, unnecessary repeat examinations may result from the delayed updating of a patient's record. With RFR, items on existing patient records may be updated easily at any time. Entry

and update of information in each RFR record is subject to on-line editing. The operator is notified of unreasonable entries and prompted to correct invalid data.

In addition to the ability to enter and update patient/film data, the operator can:

- o Enter repeat studies with minimal rekeying.
- o Scroll forward and backward to display all patient film studies.
- o Print a copy of the patient's record.
- o Display another patient record by entering the X-ray number without going back to the inquiry screen.

FLASH CARD/JACKET LABEL/FILM LOCATOR

Locating the patient's film jacket, preparing the flash card, and recording the new studies on the film jacket are time consuming activities and are subject to error on a manual system. RFR automatically generates a patient flash card, an adhesive film jacket label and a film locator slip on the basis of information entered at the RFR terminal. The entire process from the arrival of the patient at the front desk to printing of the flash card, etc. in the technicians' work area takes an average of 80 seconds per patient. New patients take an additional 40 seconds.

DAILY REPORTS

Manual record keeping is susceptible to lost charges, which reduce department revenue. The RFR Daily Activity Summary Report produces a log of all procedures performed each day. This report can serve as a register for radiology billing. Each procedure reported includes: line reference number, current X-ray number, service date, patient name and birthdate, patient type (inpatient, outpatient or E.R.), procedure description, procedure category, work units, and referring physician. The Daily Activity Summary may be printed chronologically by patient arrival time in the department, in alphabetical order by patient name, and/or in numeric order by X-ray number.

RFR also generates a Daily Activity Detail Report which produces an audit trail of all patient record activity each day. This report indicates, on an item by item basis, the addition of new records as well as the deletion and update of existing records. Update items show before and after entries.

STATISTICAL REPORTS

When using a manual radiology film record system, utilization reports and statistical summaries are difficult to develop and time consuming. Many reports required for effective personnel and equipment management and to forecast department needs cannot be generated on a regular or timely basis. In contrast, RFR produces

complete statistical and management reports virtually on demand.

The Procedure File Listing shows the daily, month-to-date, and year-to-date totals for each procedure broken down into inpatient, outpatient, and emergency room categories. This report can be printed in alphabetical order by procedure name, by procedure name within procedure category or in virtually any order specified by the operator.

The Procedure Summary Report prints totals on a procedure category basis. Up to 36 procedure categories can be assigned. Procedure and work unit totals are generated for inpatient, outpatient, and emergency room. Also included are outpatient and emergency room visits. Grand totals, for each category, are also accumulated. The report consists of three parts providing daily, month-to-date, and year-to-date summaries. Both the Procedure File Listing and the Procedure Summary Report are useful in personnel scheduling and equipment budgeting since these reports identify the most frequently requested services as well as those services for which demand is minimal.

FILM TRACKING

On a manual system, no easy, accurate method is available to keep track of films loaned to other institutions or doctors. With RFR, each film record includes a location code. The RFR Film Location

Update Utility allows each patient's record to be quickly updated to reflect the current location of a single film study or the patient's entire film jacket. Letters can be automatically generated requesting return of overdue films on loan to other institutions or doctors. The RFR film tracking feature indicates the current location of each study performed since patient record inception.

INACTIVE ACCOUNTS

With a manual system, purging of inactive film records is both labor intensive and error prone. With RFR, patient records inactive for a specified period can be listed, saved to diskette, and purged automatically. Records to be purged can also be selected individually. Purging of inactive records includes logic to retain records of adult and minor patients until statute of limitations criteria are satisfied. A list of records to be purged in X-ray number order facilitates the actual pulling of the inactive films.

ACCESSABILITY/SECURITY/BACKUP

During periods of heavy activity, the limited accessibility and labor intensity of a manual card file system become a bottleneck, preventing efficient retrieval of patient film information and impeding patient flow. This bottleneck unnecessarily extends the patient's time in the X-ray department, wasting equipment and personnel resources. Additionally, the card catalog system is

vulnerable to unauthorized access and irretrievable destruction. There is no backup for a manual card file system.

RFR allows multiple users to access and enter patient information simultaneously. The number of simultaneous users of the RFR system is limited only by the number of terminals on the computer. An alphabetized Patient Summary Report, in telephone directory format, lists patient name, date of birth and X-ray number, allowing rapid location of films during periods when the computer system is undergoing maintenance.

The RFR Security Log-On feature limits system access to authorized users. Two levels of access are available: complete and restricted. Clerical personnel, assigned restricted access, cannot perform potentially destructive operations.

RFR supports a complete data backup system. On a weekly basis, an image or SAVALL of all data files is copied to a set of diskettes or magnetic tape. DAYEND processing saves each day's file activity between the weekly SAVALLs. Four SAVALL/DAYEND sets are rotated on a monthly cycle providing multiple backup levels. Restoration of RFR data files, if ever needed, is accomplished by restoring the SAVALL image and then incrementally loading the DAYEND files.

INTERESTING CASES RETRIEVAL

With a manual system, there is no simple, practical way to identify patient records with a common diagnosis. The RFR Film Study Utility enables the radiologist to extract X-ray records based on any chosen patient profile. This program is extremely useful in extracting interesting cases from the film files. For example, using the RFR Film Study Utility it would be a simple matter to obtain the names, X-ray numbers and current film jacket locations of all male Negro patients, 40 years old or older, diagnosed with sickle trait who had dorsal or lumbar spine studies since 1980.

FUTURE CAPABILITIES

National Medical is continuing to upgrade its Radiology Film Retrieval system. Planned RFR enhancements include:

- o Patient/Room Scheduling
- o Bar Code Film Tracking
- o On-line Interesting Case Inquiry
- o Generator Exposure Calculation
- o Host Computer Interface

ELECTRONIC MAIL IN RADIOLOGY

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As computer technology becomes increasingly accepted as a tool for managing information in health care institutions, one expected result is rapid growth in the availability of computer systems. The concept of electronic mail is one which will gain popularity in direct proportion to increased hardware availability. It is the purpose of this paper to discuss the electronic mail system currently used in the Radiology Department at the Massachusetts General Hospital. In order to achieve this purpose, consideration will be given to the technical and operational aspects as well as to current uses and benefits.

Before beginning an explanation of the system, however, it would seem worthwhile to provide a general definition of the basic concept. Electronic mail, sometimes referred to as computer mail, is a message delivery system which uses a computer as a storage and delivery intermediary, most often utilizing CRT computer terminals as the input and display devices.

From the user's point of view, there are two functions used to operate the system: the SEND function and the READ function. In order to send a message the user must first locate a CRT and call the SEND function. At this point, the program requires entry of a user identification code. At the MGH, this identification sequence consists of the user's initials and a confidential, four character alphanumeric code. Once the eligibility of the sender

has been ascertained, the recipient must be identified. This is done either by initials or name. If neither is known, entry of at least three letters of the last name will prompt the computer to search the list of all possible recipients and present a choice of those with the particular letter combination. The CRT terminal then shifts to an off-line state and allows the sender to input and edit the message as desired. When input is completed, the message is "sent" to computer memory via line by line transmission.

The other half of the system involves the use of the READ function. Typically, the recipient is notified that there is mail waiting after having identified him/herself to the computer when using another function (usually signing or transcribing of reports). Of course, it is also possible to use the READ function directly to determine whether or not mail is waiting. The READ function is quite simple. After a similar user identification sequence, all messages are presented, both signed and dated, in the order in which they were sent. After reading, the user is given the option of either saving or deleting the message.

Another equally important way of looking at the system is from an analysis, design and programming standpoint. The extent to which the message network is developed depends primarily on the hardware configuration. In the MGH Radiology Department the electronic mail system has been implemented on a DEC PDP 11/70

computer which drives approximately thirty terminals. These terminals are located throughout the department, allowing for reasonable accessibility. Aside from hardware, there are several other conditions necessary for effective implementation. A finite list of potential users is needed to facilitate name searches and message assignments. Confidentiality is maintained through the use of an alphanumeric code for each user.

The programs which run the mail routine are written in MUMPS, as are all the programs which make up the computerized reporting system. They can be divided into essentially three subroutines which include initializing the CRT for text editing, sending mail and reading mail.

The range of applications for electronic mail is limited only by the needs and imaginations of the users. Perhaps the largest single use for the mail system has been by transcriptionists and radiologists to resolve questions regarding particular reports. Both parties often find this system to be the fastest and easiest method of clearing up problems, due mainly to familiarity with the CRT and the reporting system in general. Other current uses have ranged from personal memos to requests for racquetball partners. It should be noted, however, that great care was taken to insure that each message displays a signature and date to alleviate the possibility of anonymous notes of one type or another!

There are a variety of benefits which have resulted from the implementation of an electronic mail system. Perhaps the most basic is, as you might expect, the facilitation of information flow within the department. As long as the message system continues to be more convenient and checked more often than conventional mail boxes, efficiencies will continue to be generated. In addition to the most obvious results of the system, there is also the possibility that by encouraging CRT usage, radiology reports will be transcribed and signed more quickly.

In very simple terms, the electronic mail system represents a useful element of the overall reporting system whose marginal cost of development and implementation was very small. The hardware was not changed during implementation and the initial programming time was on the order of one day. As a result, all of the benefits mentioned were provided at almost no extra cost. It has proven to be a popular addition as well. Over the course of a recent forty day study, radiologists and secretaries used the system for a total of 429 messages. Finally, and perhaps most importantly, to the extent that these programs can and do relieve user anxiety about computers in general, then the entire system has been made more effective.

COMPUTER PRESORTED DISTRIBUTION OF RADIOLOGY REPORT COPIES

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The use of either typewritten or computer printed multiple part forms for radiology reports is commonplace. The use of a multiple part form is an effective way of producing necessary copies. Most commonly these copies are the original Medical Record (or chart) copy, a Radiology Master Folder copy, a referring physician copy and a billing copy.

This report will discuss an established system at the Massachusetts General Hospital (MGH) which uses computer presorting of all copies of Radiology consultation reports to minimize manual labor and expedite distribution. Prerequisites for presorting of all categories of report copies include electronic report signature, separate printing of each category of report copy and extensive information on destination.

In Massachusetts, legal signatures are required on the medical record and professional billing copies. Given online electronic signature, originals of both copies with legal signatures are easily produced. Note, however, that if only one legal signature per report is required, presorting of other copies can be done if the computer is informed of which reports have been signed. The Hospital of the University of Pennsylvania uses this approach.

100% of all reports issued by the Radiology department

are processed via the computer reporting system in operation at MGH since 1978. System inputs include direct transcription on CRT-keyboard terminals of dictated reports and coded entry of optional standard reports. The resident and staff radiologists review the reports on CRT terminals. Corrections can be made by dictation or by the radiologist at the terminal using an editor program. Signature of reports is by "computer key signature" on the terminal, replacing signature with a pen on an actual paper version of the report. Each radiologist has a confidential "key signature" comprised of four alphanumeric characters which he or she enters to "sign" the report. This signature is as legal as a handwritten signature. As reports are available for review instantly after transcription on any terminal within the department, review and signature of reports is expedited. This system eliminates the original, time consuming routine of sequential signature by first the resident radiologist and then the staff radiologist, and it obviates the manual sorting of reports into resident and then staff radiologist mailboxes for handwritten signature. Both of the involved radiologists can access the report for signature as soon as it has been transcribed.

Electronic signature made possible the separate handling of all report copy categories, because medical record and billing copies of the same report, each with a legal signature, could be printed separately. It was no longer necessary to

keep the multiple part forms together for the review and signature process.

In years past, multiple part forms were used in the manual mode as well as during the early operation of the reporting system at MGH. Various copies were different colors and were appropriately labeled as is common practice. Up to four and possibly five readable copies were obtainable, although the quality of the fourth and fifth copies was sometimes poor. Following review and signature, each copy of each individual report had to be separated, one from another. Each copy had a separate destination, and each required a different sorting routine. If continuous feed stock was used, each report had to be burst either by hand or by machine from those on either side of it. At this point, the manual sorting of copies according to various routines could begin. The quality of this sort varied with the data available and the training and ability of the person doing the sorting.

In 1979, it was decided to print each report copy separately to decrease or eliminate the manual sorting and bursting problems. Thus, all of the Medical Record copies are now printed together. The Radiology master folder copies are printed together in a separate run and so on. Separate printing enables separate computer presorting whereby each category of reports will be printed to match the order of

Table I

MGH SORTING AND PRINTING PARAMETERS
RADIOLOGY CONSULTATION REPORT COPIES

Copy Type	Primary Sort	Print Order
1. Medical Record copy (chart)		
a. In-patient	Patient location at time of sort	Physical delivery route
b. Out-patient	All out-patients and discharged in-patients	Unit number terminal digit
2. Provider copy		
a. Clinic	Requesting clinic	Physical delivery route
b. Private patients	Clinician	Physical delivery route
3. Radiology Master Folder (MF) copy	MF location at time of sort	Shelf order for each file room plus smaller groups
4. Billing copy	EW, out-patient and in-patient groups	Unit number terminal digit within group

distribution. Table I shows the sorting routines and the order of printing for each report copy category.

Probably the most important of all is the report which

goes to the medical record. The group of medical record copies awaiting printing is first sorted into in-patient and out-patient groups. The in-patient group is then sorted by patient care areas. At MGH, the in-patient census information, giving room and bed numbers for all in-patients, is updated by transmission of new information to the reporting system as often as new data is available. The use of this current patient care area and bed location information precludes the inadvertent routing of the medical record copy to a previously correct patient care area from which the patient has subsequently been transferred. The delivery of these medical record chart copies is by messenger, and the order of printing is by care area according to the actual route the messenger walks. The group of reports for each care area is preceded by a face sheet, and the messenger merely tears off the correct group of reports from the continuous feed group which he or she is carrying from one care area to the next. MGH does not have terminals on individual patient care areas; if a hospital had a printer on each patient care area, the report could be transmitted electronically to that printer rather than hand carried.

The medical record copy for out-patient studies is further sorted by unit number into terminal digit order. These out-patient medical record copies are delivered to the Medical Records Department for filing into patient charts. Certain MGH

neighborhood health centers maintain their own medical records departments. Their chart copies are printed separately and delivered directly via house mail.

The next major category of report copy is the provider copy. Although the majority of provider copies go to individual clinicians, a significant number of patients are also seen in various clinic settings. The care provided in the clinics is by many physicians, including senior attending physicians whose primary activity is their own private practice. When the requesting location is a clinic, the report will be sorted and printed with the other reports from that clinic. For clinics within the physical boundaries of the hospital, the copies are presorted in the order of hand delivery. The nursing staff of the clinic reviews each report to determine what expected or unexpected action is appropriate for that patient. This approach means that prompt attention will be given to the needs of the patient, regardless of whether the physician who saw that patient is there daily or every other week.

For private patients the ordering physician is entered and verified against a continuously updated computerized clinician directory. The provider reports for private patients are sorted by clinician and then according to clinician address. The print order is the actual route walked by the

messenger who hand delivers the reports to offices within the hospital. Another group is printed with special addressing to permit folding and stapling for house mail delivery, and a third group is printed and addressed for delivery in window envelopes via U.S. mail to referring physicians remote from the hospital. A fourth group of miscellaneous problem cases is handled individually. Most of these are clinicians whose names are not in the directory. Once the current addresses are determined, these clinicians are added to the directory for future reference and the reports are delivered.

The Radiology master folder (MF) copies are sorted and printed at night. The two major groups, those which will be filed in MFs in the active and main film libraries, are each printed with the reports presorted into shelf order. The film librarian walks down each aisle only once, tearing off the next report and putting it into the proper folder. Of course, two or more reports on the same patient are automatically printed together. The identity of the MFs in either shelf area is known from the optical pen reader master folder tracking system. The location of other master folders for which reports are ready is also known, and these reports are printed in labeled groups for filing.

The fourth category of report copies, that of professional billing copies, is presorted according to patient

location at the time of scheduling into three groups: in-patients, out-patients and emergency ward patients. Within each group the print order is by unit number terminal digit.

In addition to the four major report categories mentioned above, there are several other categories of report copies: preliminary copies, intra-departmental copies, corrections-feedback copies, White 1 recheck copies and personal copies.

The preliminary report copy is part of providing printed reports to in-patient floors as soon as possible. Chart copies are printed five times a day. At about 8:00 p.m. every evening, the medical record copy of all in-patient reports which have been staff radiologist signed since the previous print run are printed. Subsequent to this, a special printing of all other previously unprinted in-patient reports which have been transcribed but not signed is done on paper of a unique color which is marked "Preliminary copy, not reviewed by the radiologist." Both of these print runs are presorted for immediate delivery by hand to the in-patient floors as previously described.

The intra-departmental copies are printed in sets for a few sections of the department. Printing order is alphabetical by section for delivery to the section.

The correction-feedback copies are generated for the benefit of the transcriptionists and resident radiologists. Any report which has been edited is reproduced with the changes marked for review to provide feedback on various errors. The sorting and printing routine is alphabetical by resident and transcriptionist initials for distribution into departmental mailboxes.

White I Radiology is a four-room area which does Emergency Ward patients 24 hours a day. The purpose of the White I recheck copy is to aid in the staff radiologist checking of resident dictations done when a staff radiologist is not present. The sorting and printing for these copies is done simply by using the terminal digit of the unit number for all recheck cases not yet printed. These reports are displayed with the radiographs on a multiviewer for "re-checking" by a staff radiologist.

Lastly, any radiologist can flag a report so that a report of it will be printed for his or her personal use.

An attempt at measuring the efficacy of computer presorting of report copies has been made in the form of a cost/benefit analysis (Table II). It shows the portions of the benefits and costs which are directly measurable in dollar terms. The measurable costs are primarily due to hardware,

Table II

COST/BENEFIT OF
SEPARATE REPORT COPY PRINTING

Quantifiable Benefits	$	Quantifiable Costs	$
1. Full time ripping/sorting position	14,030	1. One extra printer	795
2. Transcriptionist time saved preparing outside clinic/clinician copies for delivery (15hrs/wk)	6,270	2. Extra computer time (marginal cost)	0
3. Filing time saved		3. Initial programming (1 programmer-week)	120
Medical Records (4hrs/wk)	1,400		
Radiology filing (20hrs/wk)	7,710		
4. Time saved for hand delivery of clinician/clinic copies and in-patient medical records copies (5hrs/wk)	1,750	4. Systems analysis (2 person-weeks)	195
Total benefits	$31,160	Total costs	$ 785

Table III

NON-QUANTIFIABLE BENEFITS OF SEPARATE REPORT COPY PRINTING

1. Better patient care delivery
a. Decreased time between examination and reported results
b. More accurate report destination determination
c. Increased readability - each copy is an original
d. Significantly reduced risk of misplaced reports
2. Departmental efficiencies
a. Accurate and timely forwarding of intra-departmental copies
b. Volume of paper circulated and handled reduced

programming and analysis. In order to put costs on a yearly basis, hardware and software costs have been amortized over three years. With these assumptions the benefit/cost ratio is 16.2.

There are also significant benefits which are difficult to represent in dollar terms (Table III). Increasing the speed of report delivery is of obvious importance. The speed of a computer sort and less physical handling of report copies lead directly toward this goal. It is also important to note that

less handling and sorting by humans reduces the risk of misplaced reports. Increasing delivery speed is beneficial only if the report is directed to the correct destination. Again, the use of valid information during the sort has increased accuracy as well. The readability of reports has improved as all "copies" are originals.

In summary, computer presorting of radiology report copies is a relatively inexpensive way of accomplishing several tasks more accurately in far less time. The benefit/cost ratio is greater than 16 to 1.

OPTICAL BAR CODE TECHNOLOGY FOR USE IN RADIOLOGY

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INTRODUCTION

Optical bar codes have become well-known to much of the general public because of their frequent use in supermarkets at automated check-out counters. In the early 1970's, prior to the automation of the supermarket, bar code technology was introduced to radiology at the Massachusetts General Hospital where bar codes were used to identify radiology film folders.[1,2] At about the same time, a commercial group introduced the AMES Color File system for control of the radiology film library.[3]

At the Mallinckrodt Institute of Radiology in 1975 a microprocessor-controlled bar code decoder capable of reading several different types of bar codes was designed and constructed.[4] At the same time, a computer system was developed to analyze the performance of the various analog and digital components of a bar code reader system. Since that time, a wide variety of commercial bar code products have been evaluated and installed at the Institute.

In recent years, bar codes and other optical encoding techniques have found wide-spread application in a number of radiology departments[5,6] not only for tracking film folders, but for tracking patients, coding diagnostic reports, and entering various types of data into radiology computer systems.

TABLE 1

COMPARISON OF OCR AND BAR CODE TECHNOLOGY

	Cost of Decoders	Cost of Printers	Offset Printing Of Codes	Ease of First Read	Human Readable
OCR	$2000	Can use standard typewriter	Yes	Good	Yes
Bar Codes	$1000	$600 - $6000	Yes - Some Codes	Good - Excellent	Text must accompany

ALTERNATIVE CODING TECHNIQUES

Coding techniques are useful in radiology to facilitate the rapid and accurate identification of items such as patient documents or film folders. A variety of technologies have been proposed for this purpose, the most promising of which include magnetic encoding, optical character recognition, and optical bar code technology.

Magnetic encoding is used commonly as an encoding method for credit cards. Magnetic stripes can be recorded at very high density and have the interesting property that the encoded information can be changed at a later date. Magnetic coding is more expensive than optical encoding, however, and it has proved easier to affix optically encoded labels to patient documents and film folders. For these reasons, magnetic encoding techniques have not yet seen a great deal of use in the radiology field.

Optical character recognition (OCR) coding is attractive because it is inherently man and machine readable (see Table 1).

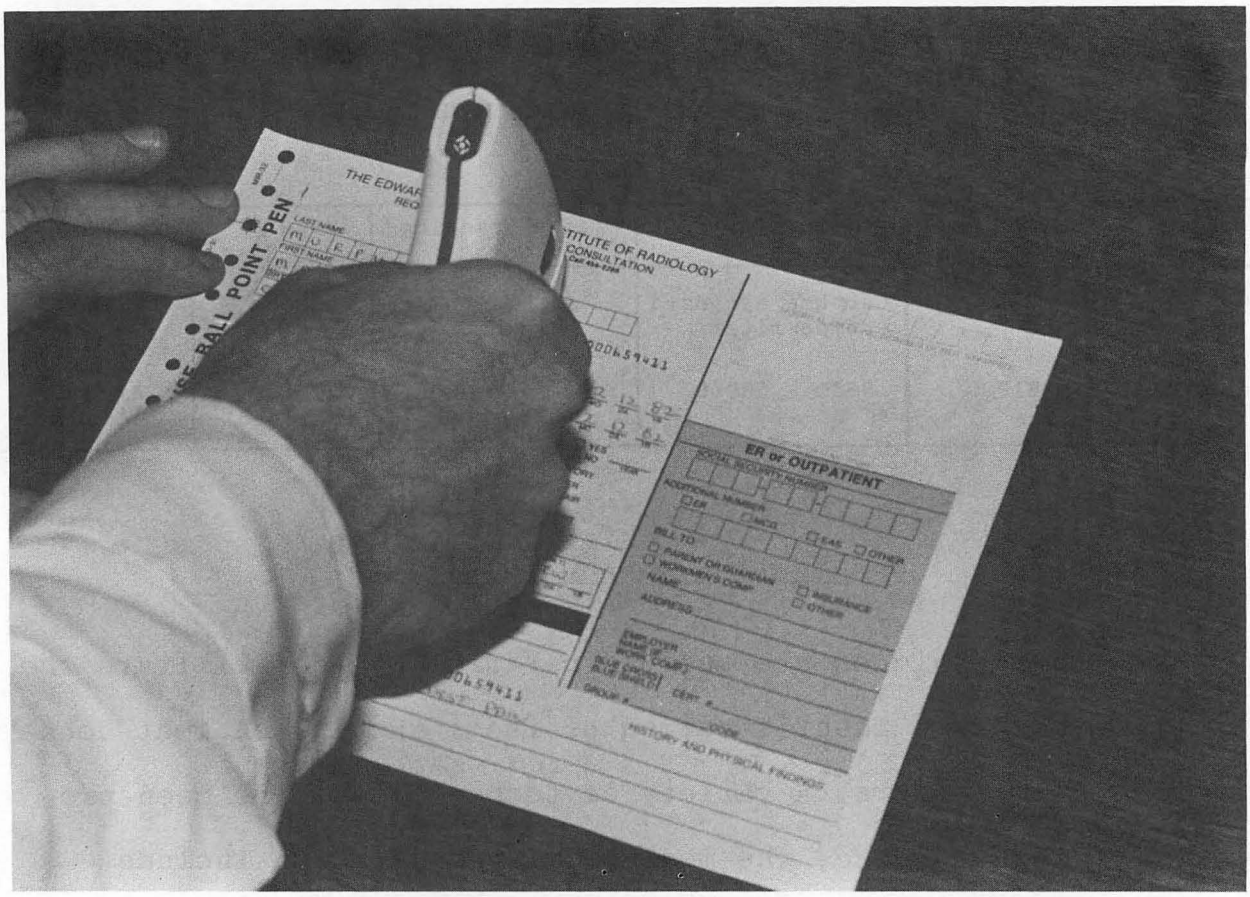


Figure 1. - Patient arrival is indicated by sweeping on OCR wand across a patient identification number. At the Mallinckrodt Institute, all examination request forms are preprinted with a machine readable number.

The OCR technology developed for point-of-sale applications involves the use of a hand held wand to decode numerical information, and it is this technology which is most appropriate for radiology applications (Figure 1). OCR labels can be produced inexpensively on a variety of printers, including a standard typewriter using a standard font. Furthermore, it is possible for a commercial printing company using an offset press to produce patient forms which include sequential OCR identification numbers.

On the other hand, OCR readers are more expensive than bar code decoders and there is no indication that this price differential will change significantly in the near future. Until recently, high quality OCR printers were considerably less expensive than bar code printers, but a recent drop in bar code printer prices has minimized this advantage. Perhaps more important, equipment designed to read human readable characters is not as accurate (one substitution error in ten thousand characters)[7] as a well-designed bar code system, and an OCR reader is slightly more difficult to use, requiring more care in aligning and sweeping the wand.

OPTICAL BAR CODE TECHNOLOGY

Operation And Terminology

Black and white bar codes come in a variety of shapes and sizes (Figure 2). Codes can be read with a fixed beam scanner by moving the code in front of the scanning beam.[8] This is useful in supermarkets or on an assembly line where products must be identified as they pass by on a conveyor belt. An alternative method of decoding employs a hand-held wand which can be swept across the bar code (Figure 3). It is this approach that has found wide acceptance in the field of radiology.

A wand used for decoding contains a light source which is directed toward the bar code. Reflected light is then detected by a light-sensitive diode within the wand. Typically, the light source

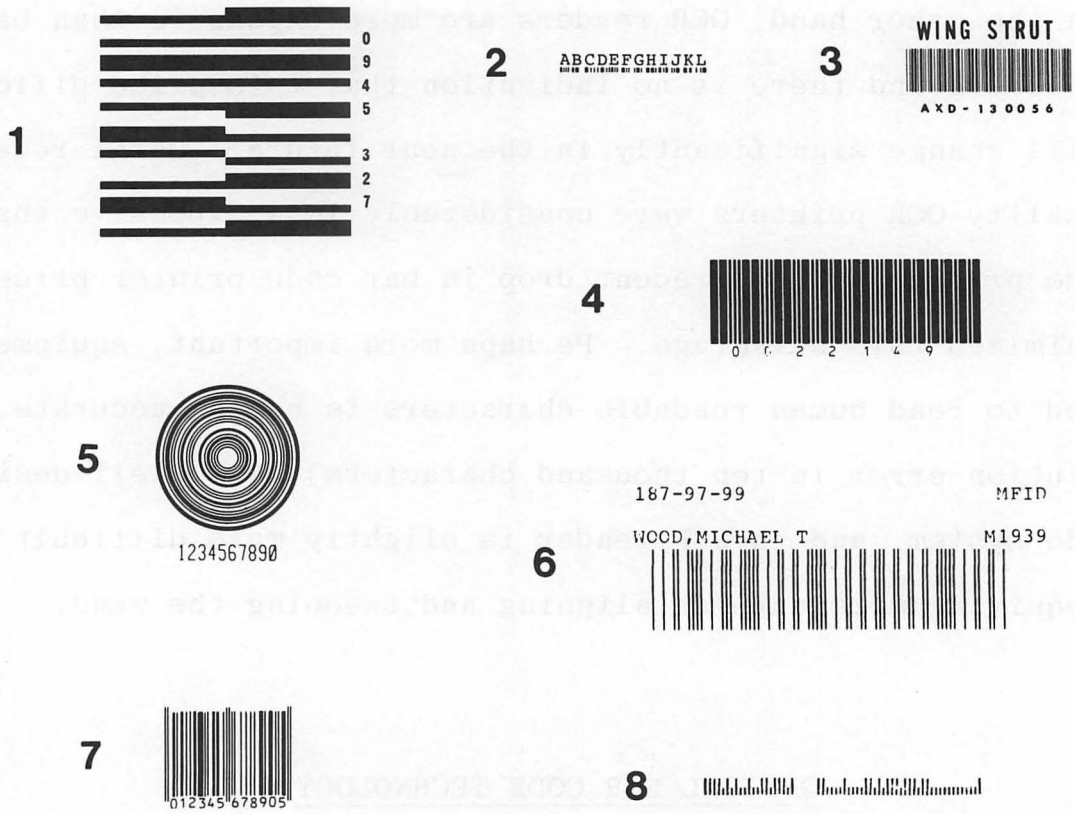


Figure 2. - Representative bar code samples. (1) Decimal code suitable for reading with a wide angle scanner. Wide angle scanners can be used to identify automobiles or railroad cars. (2) Miniature bar code used with optical page reader. (3) Code 39, an alpha-numeric code. (4) Black two-of-five bar code. (5) an omnidirectional bar code symbol. A patent for the first circular bar code was applied for in 1949. (6) White two-of-five code of the kind used at Massachusetts General Hospital. Printed on a letter quality printer, these codes were subsequently used at the University of Pennsylvania and the Mallinckrodt Institute of Radiology. (7) Universal Product Code, commonly used in supermarkets and point-of-sale applications. (8) Bar code used by the U.S. Postal Service.

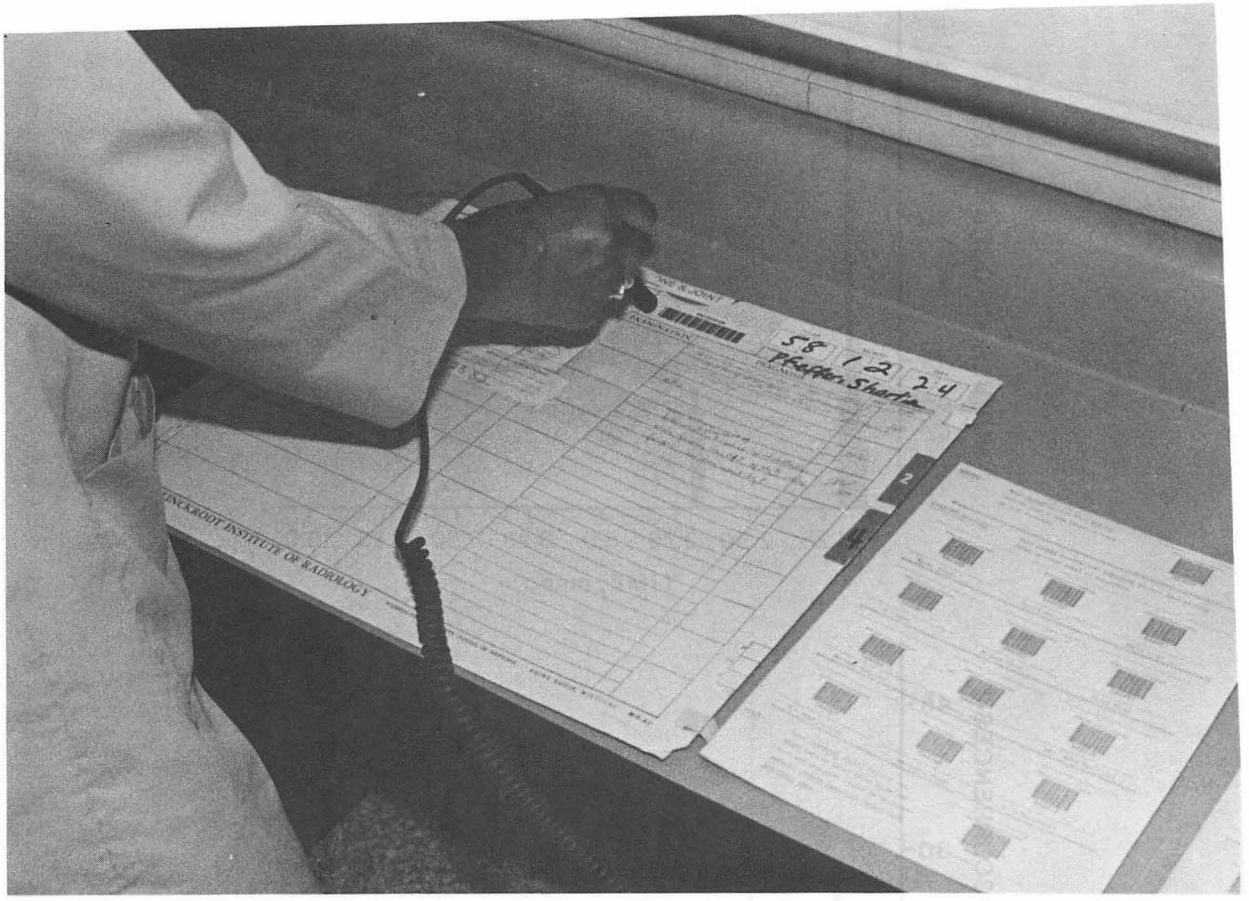


Figure 3. - Film jacket arrival is indicated by sweeping the identifying bar code with a hand-held wand.

employs either visible light (a helium neon laser) or light from the near infrared spectrum (a gallium arsenide solid state light source). As the wand sweeps across a series of bars and spaces, an analog signal is generated, proportional to the light reflected to the wand. After shaping the analog signal, the decoder must separate bars from spaces and determine whether they are wide or narrow. Poor print quality or an incorrect position of the wand makes the separation of bars and spaces, and hence the decoding operation, more difficult (Figure 4).

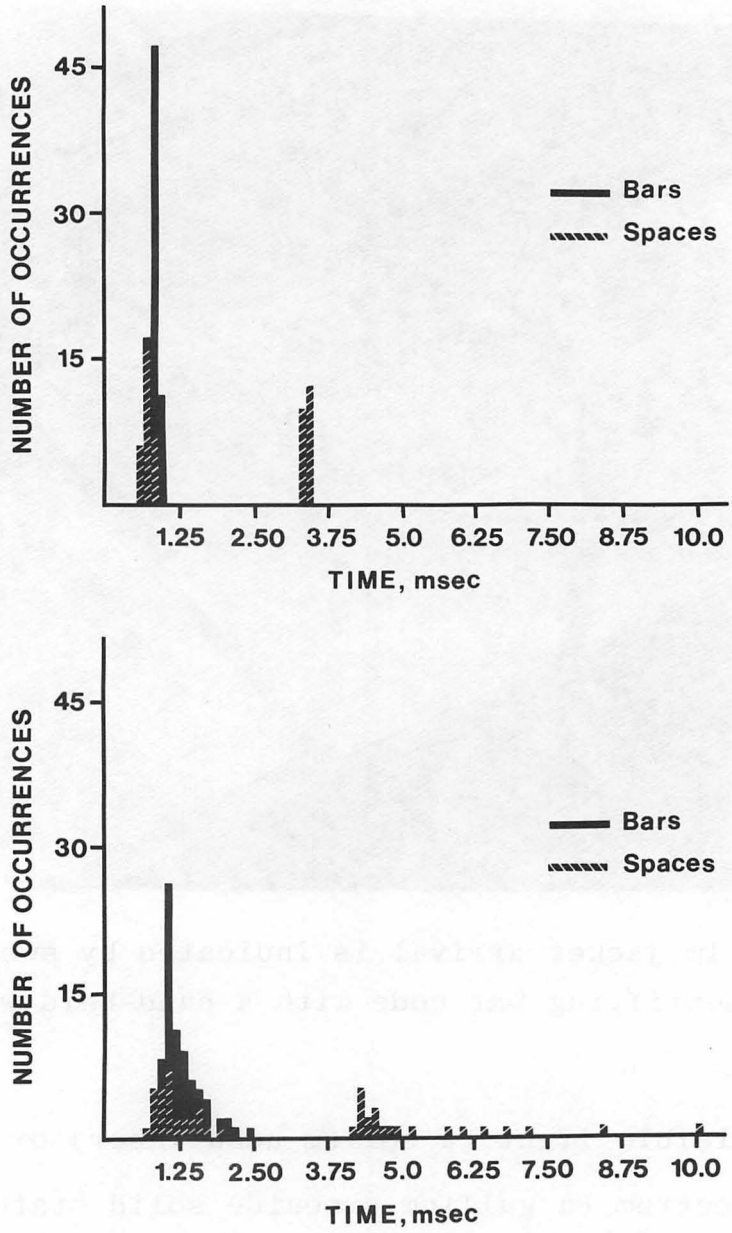


Figure 4. - These graphs indicate how long it takes to sweep across the individual bars and spaces of a typical two-of-five bar code.

TOP: During a sweep at constant speed, there is clear delineation between the wide and narrow elements.

BOTTOM: During a careless hand-held sweep across the same bar code, changes in speed create a less precise distribution, making the decoding process more difficult.

Some important terms used in describing bar code technology include the following:

Skew - If because of an inaccurate printer, bars and spaces are incorrectly aligned (printer skew) errors can occur in the decoding process. If a wand is not swept across the bar code in a straight line (wand skew) the apparent width of the bars and spaces as detected by the decoder may change. Well-designed bar code decoders can tolerate considerable wand and printer skew.

Discrete Code - In a discrete code, each encoded character is separated from its neighbor by an intercharacter space. This is in opposition to a "continuous" code where no intercharacter space exists. Discrete codes lend themselves to printing on an offset press.

Self-Clocking - When using a hand-held wand, it is typical for the wand to change speed as it passes across the bar code. As the speed of the wand changes, the apparent width of the bars and spaces (as reflected in the analog signal) will also change. A self-clocking code contains fixed width elements which allows the decoder logic to compensate for varying velocities and accelerations.

Self-Checking - Incorrect decoding of the information contained in a bar code will result in substitution errors. Certain bar code symbologies have features which minimize the likelihood of substitution errors. These codes are known as "self-checking" codes.

A check digit, at the beginning or end of the bar code, is a more explicit method of preventing substitution errors.

First-Read-Rate - A number of factors contribute to whether or not a bar code can be read easily. The first-read-rate indicates the percentage of times the bar code will be successfully decoded on the first sweep of the wand. A high first-read-rate is important if user frustration is to be avoided. With good quality bar codes, laboratory first-read-rates should average in the neighborhood of 98-99%, but in the "real world" of typical radiology departments, first-read-rates are likely to be something less than this.

Code Alternatives

Information can be encoded in bar codes in a variety of ways. Each method has its own advantages and disadvantages, and as a result a number of commercial bar code symbologies have been developed. Some of the more common types include the following:

Two-of-Five Code - In this code, each numeric character is represented by a group of five bar code elements, two of which are wide and three of which are narrow (hence the term two-of-five). The position of the wide elements within the group of five determines the coded number. Two-of-five code can be "black" (the most common form) where the information is encoded in wide and narrow bars, separated by spaces which contain no information (Figure 2, example 4). In a white two-of-five code, information

is encoded in spaces of varying width, separated by bars of standard width (Figure 2, example 6). Two-of-five code is a discrete, self-checking code of relatively low density. It is, therefore, not a good choice where space is limited, but usually is quite satisfactory for large areas such as film jackets. "Interleaved" two-of-five code is a continuous variant in which information is contained simultaneously in both bars and spaces, producing a higher density code.

Three-of-Nine (Code 39) - This code, introduced by Intermec in 1975, specifies nine elements for each character, three of which are wide (Figure 2, example 3). This permits the encoding of a full alpha-numeric character set. This is a discrete code with strong self-checking characteristics. It is currently the most widely used industrial bar code and has been chosen for the film library system at the Mallinckrodt Institute.

Universal Product Code (UPC) - The Universal Product Code was adopted by the grocery industry in 1973 (Figure 2, example 7). Typically, this ten digit numeric code is read at supermarket check-out counters by passing the label over a bottom-reading laser slot scanner, but it can also be read by a hand-held wand. The code was designed with several criteria in mind which are important to the supermarket industry. It had to be read in an omnidirectional fashion, and the code had to be one that could be printed in high volume using a wide variety of printing processes and printing inks. This code is difficult to print with devices

other than printing presses, and it is seldom used outside the supermarket or point-of-sale industry.

Other codes which have been used in radiology include Codabar (Welch Allyn) and Ames (Ames Color File Corporation). These are both numeric-only, discrete, self-checking codes which are quite acceptable for most radiology applications.

Bar Code Printers

The method of producing a bar code is important, for the quality of the code has a great deal to do with whether it will be read easily and accurately. In situations where it is feasible, high quality bar codes with sequential numbers can be preprinted on requisitions or film folders using an offset press. This applies only to discrete codes (e.g., two-of-five, Code 39, Ames, etc.).

In many radiology applications unique identification numbers must be printed at the time of patient arrival. For these situations, bar code printers under computer control must be available in the radiology department. Traditionally, high quality label printers designed exclusively to produce bar codes have been relatively expensive ($6,000 or more). This cost can be prohibitive in situations where printers are required in several diagnostic areas. Recently, several lower cost alternatives have become available. A thermal bar code label printer using heat sensitive paper (approximately $2,000) has recently been introduced. In

addition, the recent introduction of several new matrix printers with graphic fonts have made it possible, at relatively low cost, to produce a wide variety of documents which include bar codes. Matrix printers vary in cost from a few hundred dollars to a few thousand dollars. Certainly the quality of print obtained with a home-computer-style matrix printer is not as good as that obtained with a dedicated bar code label printer, but in many radiology applications, considerations of cost may outweigh considerations of quality.

The production of a high quality bar code depends not only on the quality of the printer itself, but on the materials associated with the printing process. Print quality is highly dependent on the type of paper that is used and the amount of ink-spread that the paper tolerates. Ribbon type and quality is also important, and particularly with matrix printers where print quality is marginal, ribbons must be changed on a regular basis, for as the ink content of a ribbon is depleted, non-scannable bar codes may result.

In situations where labels will be scanned repeatedly or subject to repeated physical abuse, it may be advisable to purchase resin-coated labels to enhance the label's stability. This is useful, for example, when a label is to be affixed to an identification card in a doctor's wallet. A similar result can be obtained by applying a piece of transparent tape over the printed label.

Careful attention should be given to all the factors which go into producing the label, for they interact to affect the quality of the bar code system. A high quality code will lead to a high first-read-rate which will minimize the frustration of the user. Furthermore, the likelihood of substitution errors is inversely related to bar code print quality.[9] Thus a high quality bar code printer will produce the best results, but in situations where for reasons of cost the highest quality of printer is prohibitive, a thoroughly satisfactory system can be assembled less expensively.

Bar Code Wands

A radiologist selecting a bar code system will often be asked to choose between a visible light wand and an infrared wand. The infrared wand is less sensitive to reflections from background lighting, but not all printer ribbons contain inks which reflect this part of the spectrum satisfactorily. In these cases, the visible light alternative may be preferable. Ribbons with a high carbon content usually provide reflectance in both spectral bands. A "low-resolution" wand may be preferable for reading labels printed with a dot-matrix printer. It is advisable, in every application, to evaluate each case individually. Each type of wand should be evaluated on a set of the actual labels which will be used in the bar code system.

CONCLUSION

Optical bar codes provide an excellent method for accurate and automatic identification of patient documents and film folders in a radiology department. To provide optimum performance of a bar code system, an understanding of the components which affect the quality of the system is important.

Several alternatives exist with regard to a choice of bar code symbology. Most commercial codes could be used satisfactorily, although the Universal Product Code is significantly less attractive for radiology applications than some of the alternate possibilities. Code 39 provides a full alpha-numeric capability and has been introduced recently in a number of radiology applications.

A wide variety of bar code printers is now available, and very recently, the cost of those printers has decreased dramatically. It remains to be seen whether the very low cost matrix priners will be durable enough to withstand repeated use in a radiology environment, but their recent introduction provides a promising new method to produce bar codes inexpensively under computer control in various parts of the radiology department. Bar code technology, after a decade of development is now well-established in the field of radiology. It is likely that new applications and the trend toward lower equipment costs will lead to even further developments in this area in the future.

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CURRENT STATUS AND EXPECTATIONS FOR SPEECH RECOGNITION BY COMPUTERS

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INTRODUCTION

Automatic speech recognition requires that a computer be capable of accurately transcribing a spoken input into a machine or human readable form. Although speech recognition by humans basically is taken for granted, computer recognition of speech is an exceedingly more difficult task. Nevertheless, in this microcomputer era, voice communications with computers will certainly come to a successful realization.

The projected uses of this technology seem limitless; at present, however, two principal areas of application are dominant: 1) those involving data gathering and data entry, and 2) those involving control of mechanical and/or electronic devices. The applications of voice data entry are justified primarily by the economic advantages of voice as compared to alternative data entry techniques. As the cost of voice data entry terminals decreases, more applications will arise, particularly when the true costs of data capture are considered. In some cases, voice input offers advantages which far outweigh the economics and permit operations to be achieved which could not easily be accomplished using alternative data input techniques. Generally speaking, voice input is cost effective 1) when information is needed immediately without transcription delays, 2) where the operator requires a high degree of mobility, 3) where the operator's hands and eyes are busy with other tasks and 4) when the operators are not skilled at typing or cannot take extensive time to be trained.

Almost any system using intelligent CRT/keyboard terminals for data input

could use speech input terminals as an alternative. Virtually any factory or office system which is now directed by instructions from a keyboard could be controlled by verbal commands. With current speech technology, the human voice simply replaces the mechanical keyboard or computer control, often with distinct operational and economic advantages.

To date, most of the applications of speech input technology have been associated with industrial and manufacturing environments since the economics of equipment costs and manpower savings have been more easily justified in these areas. As the price of speech recognition equipment is lowered, and the performance is increased, many new applications will emerge and the technology will spread to other business areas. In these cases, speech input technology may eventually merge with source word processing technology and provide enhanced capabilities for the user for data entry, information retrieval, and text editing.

This paper will emphasize the technology and applications relating to data entry. In this regard, we will review the current state-of-the-art of speech recognition, and attempt to make some projections regarding the future status of this technology.

SPEECH PROCESSING

General

Speech processing can be broken down into three major functional areas - speech recognition, speaker recognition, and speech generation. Today, speech generation accounts for the largest share of commercial sales in speech processing and consists of products which produce audio output by either

analysis/synthesis or via direct synthesis. This technology will not be reviewed in this paper. Speech recognition products comprise the second largest speech processing industry segment and speaker recognition, a new comer to the industry is third. Many industry analysts forecast that these last two segments will experience a growth in sales in the eighties which will exceed that of speech generation sales. Speaker recognition is discussed briefly in the next section since it has potential application in maintaining and insuring record privacy. The remainder of this paper will attempt to summarize the technology, review the current status and provide an insight to the future of speech recognition.

Speaker Recognition. Speaker recognition is defined here as the capability to verify that the speaker is indeed who he says he is, or the capability to identify the speaker from a given population set. The former is the least difficult technically, and has emerged first in the marketplace. Commercial products are available which can verify a speaker from voice input once the equipment has been trained to recognize the individual beforehand. Speaker verification products range in accuracy, flexibility and price. Some vendors can provide speaker verification on the same hardware that is used for speech recognition. In today's products, speaker verification is almost completely text dependent. That is to say that the system must know in advance what is going to be said before successful speaker verification can be made. Text independent speaker verification will most likely become available in the 1985-1990 time frame.

Speaker verification products currently are installed for application

testing in the secure access marketplace. Since speaker verification utilizes a personal attribute which eventually will be able to be transmitted by telephone, it becomes a powerful and convenient technique to verify that a person located remotely to a computer is indeed authorized to enter a building, access restricted data, perform an authorized transaction or any other sensitive, personnel oriented task.

For the most part speaker recognition products are so new that this industry segment has had few forecasts ventured by industry analysts, and if the capability continues to be offered as an additional or optional function to speech recognition products, then both will be forecasted as one industry segment.

Speech Recognition

Isolated and Connected Speech. Speech recognition may be subdivided into two categories, isolated and connected. The defined difference is simple but the technical solutions are an order of magnitude apart. Isolated speech is simply speech which is made up of utterances which are separated by silence (or pause). Each utterance whether it be a number, word or a phrase, is trained and recognized as a single input. Therefore, the speaker must separate each utterance by silence when using voice input to isolated speech recognition products. The majority of currently available recognition devices recognize isolated speech.

Connected speech has no detectable silence between utterances. One of the most difficult technical problems in connected speech recognition is determining where one utterance ends and another begins since adjacent words

are altered by their neighbor (coarticulation). In spite of these difficulties, commercial products are available today which offer limited connected speech recognition. With the increased processing power of new 16 and 32 bit microprocessors and new algorithms for word boundary identification and utterance recognition, the current limitations of string count (the number of utterances allowed to be connected) and vocabulary size (the number of utterances valid in a string) should become less severe in the near future.

In a standard isolated speech recognition system, the minimum silence period between utterances which can be reliably detected by a computer is about 100 milliseconds since shorter pauses might be confused with pauses appearing within stop consonants such as b, d, g, p, t, and k. The fact that a stop gap can exceed 100 milliseconds duration when spoken by some talkers, coupled with the uncertainty of providing a sufficient pause between words, usually encourages the talker to provide a longer pause between words than may actually be required and thereby lowers the actual data input speed.

The maximum speaking rates that can be achieved with isolated speech are lower than with connected speech, but the differences are by no means overwhelming. The upper speed bound for an isolated word recognition system has been measured informally for trained speakers reading digits in random order. Rates of 120 digits/minute have been achieved consistently by the best speakers, with error plus reject rates of two percent or less. In factory environments, industrial workers have readily adapted to speaking words in isolation, and average speaking rates between 30 and 70 isolated words (or phrases) per minute have been measured for these individuals using isolated speech input systems during their entire 8-hour working day. These average

rates included peak speech rates of up to 120 words/minute.

No comparable results are available for connected speech, since until recently there has been no real-time connected-speech recognition system of comparable performance. One currently available connected speech system developed by NEC permits the entry of a limited number of words (five) in a string (spoken within a fixed time period) before requiring a pause. In this mode, even though peak rates for short strings may be relatively high, average speed is reduced by the pause required between strings. Were this limitation not present, informal tests of connected-speech reading rates indicate that maximum machine recognizable entry rates with random digits will probably not exceed 180 digits/minute over extended time periods with 250-300 digits/minute peak rates possible.

Recently, a new recognition technique has been developed by Threshold Technology called QUIKTALK™ which provides an intermediate step between previously available isolated word recognition systems and connected speech systems. Through sophisticated processing, stop gaps no longer are confused with true utterance boundaries and consequently pauses between words can be extremely short. This technique imposes no limit on how many words or phrases can be spoken in a string and consequently permits very fast data entry. Informal tests with a trained speaker have shown that 160 digits can be entered consistently over a one minute period with peak rates of 250 to 280 random digits/minute, all with greater than 99% accuracy.

Aside from increasing the speed of data entry, it is generally assumed that continuous-speech recognizers will provide a more natural input mode

than isolated speech. At high entry rates, with standard isolated word recognition systems, some speakers have trouble leaving enough separation between words to obtain satisfactory recognition results. Continuous-speech recognizers should eliminate this problem for such speakers. The problems of operating in high noise environments for continuous-speech recognizers will still have to be overcome and accuracy still must be improved for poor speakers.

Universal and Speaker Dependent Recognition. One of the main problems in recognizing speech is the wide variations encountered between individual talkers. Dialect and accent differences make the recognition of speech difficult at times even for humans. Such differences have made the search for the "universal" speech recognizer a formidable task. Although universal (speaker independent) recognition systems currently are available, the vocabulary size is highly restricted (usually between 15 and 20 words). The achievable accuracy and the fact that not all people will be understood by the system severely limit its true "universality". Speaker independent systems generally are more expensive since additional memory is required to store representative samples from many talkers. Their advantage, however, is that the user need not provide a representative voice sample before using it.

The problem of "universality" can be avoided by adapting the recognition system to the characteristics of the user whereby the system accepts training input from each potential user to construct a set of data for subsequent recognition. Since interspeaker differences are far greater than intraspeaker differences, substantially higher recognition accuracy can be achieved for a given complexity of ASR system by using speaker adaptation. It

is for this reason that the first ASR systems to be used in practical applications have almost all employed speaker adaptation. It should be noted that both isolated and connected speech can be either speaker dependent or speaker independent.

Vocabulary Size. Current technology limits the number of words or phrases which can be recognized by most speech recognition systems. This limitation is a result of various factors including computer speed, memory requirements and accuracy. Although the current isolated speech recognition technology can handle over 600 words and/or phrases, most practical applications usually require between 20 and 64 utterances. In many cases, when large vocabularies really are needed, it is possible to divide the total vocabulary into a number of vocabulary subsets and to determine which subset will be active at a particular instant by the syntax of the data entry language. This use of syntax opens up applications which would otherwise hopelessly exceed the speed and accuracy limitations of present-day speech recognition systems. Since microcomputer speed and memory size can be expected to increase with time, the remaining limitation will be recognition accuracy. New and improved algorithms must be developed to handle large vocabularies. Large vocabulary speaker dependent systems also impose a requirement on the user to "train" the system. This requirement can be both time consuming and burdensome. New techniques must be developed to minimize this problem.

Operational Considerations. There are a variety of factors which are important in achieving a practical and useful voice data entry and/or control system. Many of these factors have been discussed in detail in Reference 1.

This section will summarize those factors.

Among these considerations is the minimization of interferring acoustic signals and background noise. Typically, these effects can be overcome by the use of a close-talking noise-cancelling microphone. This type of microphone normally is worn on a lightweight headband or mounted in a handset. The use of this microphone, however, introduces other extraneous signals such as breath noise thereby requiring that the recognition system be capable of discriminating between speech input and breath noise. In addition, the requirement of wearing a headband is not acceptable to many users. An acceptable microphone which is not susceptible to background noise still remains as a major limitation to the rapid expansion of the speech recognition market.

Error rates in practical speech recognition systems must be sufficiently low to eliminate any loss of operator confidence or efficiency. Corrections by voice must be sufficiently infrequent as to be no hindrance to the accomplishment of the intended task. The acceptable error rate is dependent upon the particular application and the data entry rate. In most practical applications, the "raw" recognition error rate usually must be less than 1-2%. Voice data entry rates above 50 words per minute require lower error rates than those applications where the data rate is slow enough that the user has time to make corrections.

Recognition accuracy can be effected by a variety of causes. Obviously, the basic preprocessing techniques and recognition algorithms play a fundamental role in achieving a high accuracy. The ability of the system to discriminate the speech signal from background noise is necessary to maintain

high performance under these adverse conditions. Good laboratory performance does not insure good performance under operational conditions unless this discrimination is possible. Other factors which can effect recognition accuracy are the ability of the system to handle variations in speed, stress and pronunciation. The stability of the speaker reference data is also important, for once the reference data has been obtained, the user should be able to operate the system with little or no "retraining".

Closely related to recognition accuracy is the ability of the system to reject utterances or sounds not included in the vocabulary. In some recognition equipment, a rejection criteria can be derived and either an audio and/or visual feedback message is given the operator when an input utterance is not accepted by the system. This capability minimizes misrecognition of extraneous audio inputs. Where entries are rejected or misrecognized, corrective action must be taken. In the case of a reject, the entry may be re-entered. One approach to error correction is to provide a recognition output buffer which stores recognition results locally at the voice recognition terminal and transmits the results to the host or output device only upon receipt of a verification command. In this mode, two error-correction commands can be provided, one for erasing the last recognized word from the output data buffer and a second for erasing all entries recognized subsequent to the last verification command. The later command permits a field entry to be corrected. The correction of connected speech data input presents another problem since a long string of data potentially can be entered into the system before an error is detected. In this case it may be necessary to reenter the entire string unless more optimum

error correction techniques are developed for this mode of operation.

It is in the area of conversational, interactive feedback that the greatest potential exists to assist the user of a voice input system. Feedback to the operator can be used not only for verification, but also for prompting the user through an entry sequence, for checking syntax, format and expected values and for making special inquiries when the application requires. A very high percentage of the voice input terminals which have been installed to date are intelligent. One reason for this is that voice input is often used in applications in which the operator must perform other functions. In those situations, any assistance which can be provided by the terminal to simplify or clarify the data entry task improves overall operator productivity. A second reason is that quite frequently voice data entry is "source data entry" so that any error checking and correction which can be performed locally reduces communication and processing costs, and eliminates the long delays, high costs and potential loss of data associated with after-the-fact error detection and correction.

CURRENT STATUS/FUTURE EXPECTATIONS

Speech recognition is a technology that is proven and available today. Thousands of applications exist which are currently utilizing speech recognition cost effectively. Areas of application range from materials handling, programming, quality control and inventory control, to office automation and secure access for electronic fund transfers. With the evolutionary advances now being made in speech recognition, the application base is expected to increase significantly due to the combined effect of

increased functionality and significantly lower costs.

The timeline for speech recognition basically started in the 1950's when recognition was a research laboratory curiosity utilizing fairly large and expensive computers and crude algorithms. Government sponsored research which began in the early sixties led to several commercial offerings in the late 1960's and early 1970's. As is typical of high technology products, the progress of speech recognition research and development progress through the second decade has been exponentially increasing. By 1980, isolated speech recognition with small vocabulary sets had been reduced from a large computer, to a microprocessor and finally to a single chip. Also by 1980, speaker dependent board level products were available and the first connected speech recognition systems were announced.

Each of the defined segments of speech processing is on a different timeline of hardware implementation as a result of the differences required in processing power and algorithm sophistication. For example, isolated, speaker-dependent, small vocabulary, low accuracy speech recognition is currently available in a single chip while connected, speaker-dependent short string, small vocabulary speech recognition is currently available only in a small minicomputer or large microprocessor configuration. Other implementations such as connected, long string, speaker-independent speech recognition are not commercially available in any configuration. Functionally the following five evolutionary steps have already occured in speech recognition:

1. Isolated, Speaker Dependent, Small Vocabulary
2. Isolated, Speaker Independent, Small Vocabulary

3. Isolated, Speaker Dependent, Large Vocabulary
4. Isolated, Speaker Verification, Text Dependent
5. Connected, Speaker Dependent, Short String, Small Vocabulary

Although predicting the future is difficult at best, in the case of speech recognition some strong indicators of the sequence of future events are evident today. Based on the demand of applications and the degree of technical difficulty, the technological evolution should lead to the following three projected capabilities:

1. Connected, Speaker Dependent, Long String, Larger Vocabulary
2. Connected, Speaker Verification, Text Dependent
3. Connected, Speaker Independent, Short String, Small Vocabulary

Providing a computerized capability of speech understanding and the ability to translate ordinary human speech into a written format will remain a formidable challenge for some time. Nevertheless, implementing the capabilities mentioned above will lead to a speech recognition system having all of the following attributes:

Speaker-selectable Dependent/Independent, Large Vocabulary, Connected Long String, Automatic Isolated/Connected Recognition

Applications are supported at the turnkey systems, subsystems and the device levels by today's industry vendors. Turnkey systems are sold directly to end users, subsystems are sold to both end users and OEM's and the device

market is almost exclusively OEM oriented. Each of these three segments have distinctly different characteristics which are both market and product oriented and are to some degree dependent on the evolutionary timelines of each segment. In other words, the product differences between the three segments will in themselves change with time. For example, as microprocessors become more powerful and storage less expensive, the device market products probably will begin to take on the characteristics of today's system market products.

Earlier in this paper several evolutionary steps were defined as being on different timelines as they moved through the various stages of hardware implementation from a computer to a microprocessor and finally to a single chip. The industry as a whole also has a timeline that is pacing its evolution. The industry evolutionary steps can be defined as first being the limited industrial usage phase followed by growth and expansion, then a widespread industrial usage phase which leads into small buiness usage and finally into consumer usage. Scaled against this timeline, speech recognition is for the most part in the second growth and expansion phase. (This obviously excludes the low accuracy, small vocabulary, single chip device market which has brought a very small piece of speech recognition already to the last consumer usage phase - a trickle effect that will undoubtedly gain rapidly.)

An interesting analogy is the computer industry timeline which has for the most part progressed through all phases to become a mature industry (particularly with the advent of the personal computer into the consumer market). In comparison, the speech recognition industry is passing through

the embryonic to the growth stages and in a sense is riding on the coat tails of the computer industry trends since speech recognition utilizes computers for its own implementation. The significance of the transition from the embryonic to the growth phase for speech recognition is that there will be a simultaneous transition from a technology push of its development to that of a faster development being pulled by the market demand itself. This resultant transition inevitably will cause a price curve discontinuity from that of a linear curve to that of a typical volume-dependent learning curve. Although it is difficult to predict exactly when this major transaction will occur, several industry analysts have attempted to forecast the speech recognition market as a whole. Five such forecasts have been made by independent consultants and range from $130 million to $995 million in 1988. No one argues that speech recognition will not become a large business opportunity, they only differ as to what pace it will evolve.

If a study of application requirements by industry segment was completed, then matched to the projected evolutionary steps outlined in this paper, a profile of the products that will survive in the next decade might be forecasted. The importance of connected, speaker independent speech recognition cannot be over emphasized. Of less importance is the ability to have very large (over 300 words) vocabularies. Large vocabularies reaching to 2,500 or more words would, from this analysis, seem to be a requirement which becomes more important in the late 1980's or early 1990's. The microphone still appears to be a major input device through the next decade, but what is not clear is what type of microphone will be used. Several vendors are starting to evaluate lapel and highly directional built-in microphones to

increase the user acceptance by eliminating the requirement to wear a headset.

In summary, a few major points should be made. First, speech recognition is a viable data entry technology which is cost effective and available today. Secondly, speech recognition is currently making a transition from the embryonic to the growth market industry phase. Thirdly, technological advances will continue to be made at an increasingly rapid pace. Finally, the first three points make it imperative that the designers of tomorrow's new products give serious thought to integrating speech recognition into their products today.

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THE PROMISE OF HIGH DENSITY OPTICAL DISKS FOR RADIOLOGY

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Abstract

The high density optical disk has been shown to be a flexible information storage medium. High storage densities, rapid information access, low error rates and moderate costs all contribute to making optical storage appear attractive. In radiology, several areas of potential application for optical disks are evident. In the current analog form, the optical disk can be used in the training of radiological procedures and the use of equipment. It may also be possible to use these disks to display the lexicon that is part of an automated reporting system. The optical digital disk systems now under development provide even greater promise. The digital format will eventually allow local recording of X-rays directly on the optical disk with a high degree of resolution and help make digital radiography both practical and cost-effective. The digital disk will also provide an excellent medium for archival storage. The ability to store a large number of high-resolution X-rays along with motion and other still sequences will provide the capability to build an automated, highly interactive training aid for radiological education.

This paper summarizes various approaches being taken to storing information on an optical disk, contrasts the features of importance to the radiology community, reviews the status of optical digital disk technology and considers when and how optical storage systems will be employed in radiological settings.

1. INTRODUCTION

The analog and digital optical disk systems which have emerged in the last several years provide exciting possibilities for the radiology speciality for storing and displaying medical information. The optical systems being developed today carry the promise of extremely high density storage with attendant lower cost per unit of storage than conventional magnetic tape and disk systems. No longer is it necessary to change from one storage media to another (e.g., from magnetic disk to videotape to 16 mm film) to display various types of information. Optical disk technology has the ability to store multimedia information on one storage device making the storage and retrieval of such information considerably more convenient.

While optical storage technology and, in particular, the "video disk" is usually talked about as a single homogenous form of

data and image storage, it comprises many different approaches, with the common element of using an optical means of recording and/or retrieving information on/from the disk. Optical disk systems storing information encoded in analog format are available today and are becoming more common in the marketplace. Large scale digital, optical disk systems are under development by a number of manufacturers. These digital disk systems have information encoded in digital form and can accurately store high resolution images and digital computer data in very dense form.

1.1 Applications

Before optical and digital disk technology is reviewed for its applicability to the information system and data storage requirements associated with the practice of radiology, it is useful to consider specific areas where optical disk technology is likely to be of some use in the next decade. The first area is that of education. The radiology community is faced with educational requirements stemming from early experiences in medical school, in training for the radiology medical speciality and continuing education during a radiologist's practice. There is primary and continuing education required for X-ray technicians, nursing staffs and those associated with radiology. There is also education of the consumer or patient. All of these situations require innovative and cost-effective approaches for delivery of information in a timely and user-oriented format.

A second area where optical storage technology could be applied is in special applications associated with radiology. An example is providing visual displays for automated radiology reporting systems. At the present time the system developed by the Bureau of Radiological Health and the Johns Hopkins University, and produced by Siemens, provides a lexicon of terms and graphic

displays for automated radiology reporting. The storage and display of visual information is a primary candidate for using optical disk technology and it is applications such as the display of the radiology lexicon that need to be reviewed in light of this emerging technology.

A third area of interest is the archival storage of X-rays. Large numbers of X-ray films are today being archived in hospitals and diagnostic centers, occupying costly space and requiring sophisticated retrieval and film management systems to keep the files in order. Files of teaching radiographs, used for educational purposes across the country, are also candidates for being stored on optical disk systems. The time is rapidly approaching when digital optical systems will be sufficiently sophisticated and affordable that they need to be considered as an approach for the primary storage of radiographs.

The final area to be considered here is the on-line capture of X-rays in a fully digital radiology environment. Radiology systems are becoming more sophisticated and it is important to determine if and when optical storage technology can be employed in prototype digital radiology systems of the future.

2. OPTICAL VIDEODISK SYSTEMS

The introduction of optical videodisk systems has opened new horizons in the field of interactive video and information retrieval. Optical videodisk systems provide, for the first time, a device that can store large amounts of image and video data with a fast, easy random access capability. Current videodisk systems use analog storage technology and future systems will use digital storage techniques. The picture quality of existing systems is limited to broadcast quality, while future digital systems promise to deliver high resolution image

quality. There are four different storage techniques currently on the market: The laser-based optical reflective and transmissive systems originally developed by Philips and Thompson, respectively, the capacitance electronic disk (CED) developed at RCA, and JVC's video high density disk (VHD). The CED and VHD systems have been primarily geared, by their manufacturers, to the continuous play, home entertainment market. The reflective and transmissive optical systems may be used in both an entertainment mode or in a more flexible educational mode through their ability to do freeze-framing, slow-motion and random access. The characteristics of these analog optical videodisk systems are outlined in Figure 1.[1]

2.1 Laser Systems

The laser-based analog videodisk systems use two different approaches. The most prevalent of the two is the reflective optical system developed by Philips. This approach employs a low powered beam of light that is focused on the surface of the videodisk and reflected back to a sensor to retrieve a signal. It is the presence and absence of microscopic "pits" on the surface of the disk that cause the reflection and the interruption of the light beam. The reflective, laser-based systems available today can store a maximum of 54,000 frames of video information on one side of a twelve-inch disk which looks much like a long-playing record. Up to 10^{10} bits of information can be stored on one side. Each side can contain between thirty and sixty minutes of video information in full color and full motion with two accompanying audio tracks. Each frame is contained on one spiral track on the videodisk. Each track has a digitally encoded address allowing for direct access to any of the 54,000 individual frames. Access times are between .5 and 2.5 seconds, depending on the location of the information relative to the read head of the laser playback unit.[2]

The other laser-based approach is the transmissive system used

MAIN SYSTEM DEVELOPER	PHILIPS-MCA		RCA	JVC	THOMPSON-CSF
System Designation	Laser-Vision-Constant Angular Velocity (CAV)	Laser-Vision-Constant Linear Velocity (CLV)	CED	VHD	Transmissive Laser (TL)
Pick up Method	Optical - Reflective	Optical - Reflective	Capacitive	Capacitive	Optical - Transmissive
Disk Rotation Mode	Constant Rotation Rate	Varying Rotation Rate Constant Track Velocity	Constant Rotation Rate	Constant Rotation Rate	Constant Rotation rate
Disk Material	Plastic with Metal Coating	Plastic with Metal Coating	Conductive Plastic with Lubricant	Conductive Plastic	Plastic-Transparent
Disk Diameter, cm	30	30	30	25	30
Rotation Rate, r/min	800	Continuously Variable 1800 to 600	450	900	1800
Playing Time Per Side, min	30	60	60	60	30
Track Pitch, μm	1.6	1.5	2.7	1.4	
Minimum Wave Length, μm	1.2	1.13	0.55	0.59	
Tracking Method	Servo to Follow Signal Track	Servo to Follow Signal Track	Groove in disk	Servo to Follow Signal Track	Servo to Follow Signal Track
TV Frames per Revolution	1	Continuously Changing	4	2	1
Stereo	Yes	Yes	Not Currently but Announced	Yes	Yes
Random Access by Keyboard Control	Yes	Yes	Not Currently but Announced	Yes	Yes
Stop Pictures	Yes	No	Not Currently but Announced	Yes	Yes
Visual Pictures During SCAN	Yes	No	Yes	Yes	Yes
True Slow Motion	Yes	No	No	Not Currently but Announced	Yes

FIGURE 1

OPTICAL VIDEODISK SYSTEMS[1]

in the Thompson-CSF player. The major difference between this player and the reflective player is that the laser beam passes through a transparent videodisk to a sensor on the opposite side. As in the reflective system, it is the presence and absence of the pits that determines if the sensor detects the light beams. The transmissive system permits both sides of the videodisk to be read without physically turning the disk over. This is accomplished by refocusing the laser to read the desired side since the disk is transparent. This system has had several manufacturing problems and is not widely available at this time. TEAC has recently agreed to manufacture the player for Thompson and 3M will produce the disks in this country.

2.2 Capacitance Systems

The other two videodisk approaches currently available, the capacitance electronic disk (CED) from RCA and the video high density disk (VHD) from JVC, are radically different approaches compared to the laser-based optical systems. Each of these systems is based on the physical contact of a metallic tipped stylus with the surface of the videodisk. It is the difference in capacitance between the pits and the absence of pits that transmits the television signal to the pickup device. The CED system developed by RCA is a "needle-in-a-groove" system, very similar to today's audio stereo technology. This approach was intended primarily for home video entertainment. It is basically a linear play system with a limited "fast-forward" capability. This system currently does not have direct access, slow-motion or still-frame capabilities.

The VHD system uses a grooveless disk. Tracking is done by a servo mechanism which follows an encoded tracking signal. This system does possess the capabilities to do direct access, slow-motion and still-frames. The VHD system, like the laser

players, has two audio tracks associated with each video frame.[1,2]

2.3 Digital Image Data on Analog Optical Videodisk

An interesting approach has been recently demonstrated for storing digitally encoded images on an analog optical videodisk. The advantage of this approach is that a digital encoding of image data can possess higher resolution than a standard television (analog) picture of the same image. Work in this area was initiated several years ago at the National Library of Medicine and has recently been further developed and demonstrated by On-line Computer Systems, Inc. of Germantown, Maryland.[3,4,5]

This method employs either a digitizing camera or a scanner to digitally encode an image. This digitally encoded information is stored in a controlling computer using an image plane. This information in the image plane is then written to a digital magnetic storage file, either on magnetic disk or tape. The digital information from the storage file is then passed through a special encoder which translates the data into standard NTSC television format and records the information on videotape. The completed videotape is sent to an analog optical videodisk mastering facility where it is used as input to the videodisk mastering process. The end result is an analog, optical videodisk that can be played on any of the standard laser-based videodisk players.

Since the information on this videodisk is an NTSC encoding of digital information, the direct playback of such a disk to a TV results in 525 lines containing light and dark areas. To play back the original image, it is necessary to send the signal coming from the videodisk through a converter, changing the NTSC

format back to digital form. This digital information is th stored in an image plane in the computer and digital image display can be accomplished on a high-resolution computer monitor.

The major advantage of this approach is the storing of digitally encoded images on the currently available analog optical videodisk. The image quality possible using digital sampling techniques has much greater resolution than using a direct analog video image. The use of this approach would provide the ability to store much higher resolution images than is possible using standard analog recording.

3. OPTICAL DIGITAL DISK SYSTEMS

Optical digital disk systems are similar to optical analog videodisk systems in that information is stored and/or retrieved using some form of optical device. For optical digital systems, these devices are generally gas lasers or lasers diodes. These devices take digitally encoded data and record that data on the surface of a spinning disk by either causing a hole to be formed in a thin metal film or in some way perturbing the coating of the disk to change its optical properties. The optical digital systems being developed are similar to the educational/ industrial analog videodisk systems since they can directly and rapidly access a portion of the disk and retrieve information. There are, however, a number of significant differences in optical digital disk systems that are important when considering their use in the practice of radiology.

3.1 Difference Between Optical Videodisk and Optical Digital Disk Systems

The first difference is that optical digital disk systems are being designed to allow for the local recording of data. Analog videodisk systems require sending a tape or film to a facility

for mastering of a stamper disk. Local recording of data requires more sophistication in the optics and electronics necessary to take digital data and to encode and record it on the surface of the disk. Because accuracy is so important, most manufacturers and research organizations experimenting with digital optical systems are adopting a form of "direct-read-after-write" (DRAW) technology. These systems position a reading laser several microns behind the writing laser. The computer controlling the process compares what was written on the surface of the disk to what was intended. If the data was not correctly recorded, it is rewritten on a new portion of the disk and the sector of the disk where the incorrect information resides is ignored in future retrievals. By using this technique, several manufacturers have been able to demonstrate error rates of less than 1 bit in 1 billion bits, a rate necessary for these devices to be effectively employed for digital data storage.

The second major difference between an optical digital disk system and an optical videodisk systems is that digital systems are primarily oriented towards display on a CRT or high resolution graphics monitor. For the most part these systems have been designed to store computer data, similar to that stored on conventional magnetic disk and tape, or digitized images being acquired from satellite sensors or other digital image acquisition devices. While optical videodisk systems are limited by the resolution available in standard TV technology, the digital optical systems can potentially deliver much higher quality images.

Another major difference is the projected cost of optical digital systems. While the media cost per bit of information stored is similar to that of an optical videodisk, the recorder/player device is considerably more expensive. While videodisk players

run from $500 to $3,000, it is fair to say that over the next several years, optical digital player/recorders will cost in excess of $100,000 with some of the more sophisticated systems priced at $500,000.[6]

A final difference to be noted here is the ease with which additional copies of an individual disk are made. The approach for producing analog videodisks has been designed for producing multiple replicas by disk suppliers such as Pioneer, Sony or 3M. Since optical digital systems record locally, they require a second recording device to copy a particular disk to make a replica. While this is not technically difficult to accomplish, the digital optical systems under development do not have as a major objective the broad-based dissemination of multiple copies of a specific digital optical disk.

For purposes of this paper, major manufacturers and media suppliers of optical digital systems were contacted to discuss recent developments and to provide an opportunity for them to discuss the performance of their products and their markets of interest. In many cases information on market plans, costs and system specifications is consider proprietary and manufacturers are only willing to release information under a nondisclosure agreement. Certain other manufacturers are actively marketing their products and have prototype systems in the marketplace or under development. The following summarizes some of the findings of importance to the radiology community.

3.2 RCA

RCA, having popularized the term "Videodisc" for the home entertainment market, is also heavily involved in the development of high density optical digital storage systems. RCA reports they are marketing their system to both government and industry and are developing products that can store computer data as well as

digitized image data. They are currently working with Livermore Laboratories, NASA, Rome Air Development Command and several oil companies to develop systems capable of storing up to 10^{13} bits. They are also exploring retail opportunities for medical applications but will also be selling to OEM's.

RCA has a read-after-write-capability and has announced a technique for developing an erasable optical disk.[7]

They are basing their system on a 14" aluminum disk coated with either single, dual or tri-layer coding of thin metal alloy (of tellurium). Their system is self-contained and control devices are a part of their system. They will also develop what they term "a personality module", tailored to meet user's needs. They are experimenting with both gas laser and laser diodes with their "GEO DISC" using laser diodes for reading.
The disk they are currently using has a storage capacity of $.72 \times 10^{11}$ bits per disk, and the jukebox system being developed for RADC and NASA will hold 10^{13} bits in a 128 disk configuration. They are achieving 1.3 million bits per track and a signal-to-noise ratio greater than 50 db. They are reporting a corrected bit error rate of 10^{-9} with a bit error rate of 10^{-8} after three years. The GEO DISC being developed for the oil companies will achieve a data transfer rate of 25 megabits per second with a jukebox achieving a one gigabit per second data transfer rate. Worst case access time to any record on a single disk is 1/2 second with 5 second access time to any data block on the 10^{13} bit jukebox system. RCA expects to be delivering their systems starting in the summer of 1983 with system costs ranging from $500,000 for their single disk system to $1.7 million for their jukebox system.

3.3 Xerox

The Xerox Corporation is considerably more guarded with regard

to information on its digital optical program, due to the sensitive nature of the market and their desire to have demonstrable equipment at the time they make product announcements. Xerox has a prototype digital optical system in place at the Library of Congress. The system is targeted for the storage and demand publication of catalog cards, both in machine readable and non-machine readable format. A prototype system is reportedly being developed by Xerox's Electro-Optical Systems Division which can be used as a computer peripheral as well as an image storage system. Reported capacity of a single formatted disk is 5×10^{10} bits. The prototype system is a direct-read-after-write system and contains control devices and data retrieval software. The input devices being used are laser scanners and direct digital input with 3 megabit per second data transfer rates. Average data access time is .333 milliseconds.

Xerox reports that they are willing to share proprietary data under a nondisclosure agreement with any organization interested in potentially purchasing a system but they are not ready at this point to announce a digital optical system product line.

3.4 Toshiba

Toshiba Corporation has recently announced its DF 2000 document filing system. This system is primarily a stand-alone filing system for office automation applications and is not targeted at storing computer data. The system incorporates a laser scanner and optical disk storage component, display component and a laser printer component. Toshiba does not believe they have adequate marketing resources in this country and will likely be selling their system to OEMs.

The system is a direct read-after-write system using a 30 cm tellurium coated disk. The reported capacity of the unformatted

disk is 5 x 10^9 bits per surface. The data transfer rate is reported to be 1 megabit per second with an average access time for information on the disc of 1 second. Toshiba is using a solid state laser diode for reading and writing and they are using a charge couple device (CCD) scanner for input to the optical disk system. They report data input speeds of 5 seconds per page and bit error rates of 10^{-6}.

Toshiba expects to have a product available during 1983 and will demonstrate their system in June at the National Computer Conference. The system will reportedly hold 10,000 pages of textual material, storing one page per disk track, and cost $120,000.

3.5 Philips

Philips, which developed the optical, reflective analog videodisk technology, has also been very active in developing optical digital disk systems. Philips indicates that they will initially be producing equipment for large scale users of computer storage, such as the federal government. Eventually, they are planning to expand their market to include dealings with OEMs. Their target area of application is the storage of large volumes of computer data.

The technology being developed is a direct-read-after-write (DRAW) capability. The system uses the Philips Air Sandwich™ disk. It consists of two disks, each coated with an information-sensitive layer, covered with a protective layer on each side. The information-sensitive layer is a 300 Angstroms thick tellurium-alloy metallic film deposited on a plastic substrate. Currently, the system is envisioned as a computer peripheral and Philips has developed an interface to the Digital Equipment Corporation's (DEC) UNIBUS. Work is also being done

on an interface to the IBM 370 and on a standard computer interface. The system is using both 175 mW Argon lasers and 25 mW Helium-Neon lasers. The disks currently being tested have a storage capacity of 2×10^{10} bits per disk and they have a jukebox facility capable of accessing five disks with a maximum access time of 5seconds. The present signal-to-noise ratio is in the 45 dB range.[8] Philips is achieving a bit error rate of 10^{-9} with little overhead for data correction. They believe that for most of their eventual users, a bit error rate of 10^{-10} will be adequate. Data transfer rates of 24 megabits per second have been demonstrated. Mean access time to a record on a single disk is in the 100 millisecond range.

Work is being done at Philips-Eindhoven, in Europe, on an erasable product, in addition to the non-erasable disks. Philips is hoping to have several products on the market in approximately three years. Initial costs will probably be in the hundreds of thousands of dollars but eventually, Philips believes, prices will be competitive with those of magnetic disks.

3.6 Storage Technology Corporation

Storage Technology Corporation (STC) has also begun a major effort in the optical digital disk field. STC envisions its optical storage products primarily as a complement to the company's existing magnetic disk and tape products and they will be sold in the same markets. They will be using their existing sales channels to IBM customers, plug-compatible machine (PCM) manufacturers and customers, and to OEMs. The systems being devised at STC are DRAW systems.

Two major development programs are currently underway. The first is in the area of media. The materials being considered

for the coating of a write-once disk are thin films of metallic, polymeric, organic dye or photochromic materials. STC would not divulge which way, if any, they are leaning at this time. STC has also undertaken research and development of semiconductor diode lasers. STC would like to substitute laser diodes for gas lasers in its read-write system by 1986. An archival life, of over 10 years is desired. However, STC will probably offer two types of media, one that is more expensive and has a longer life and a second that is less costly but will not archive as long.

The initial approach is to develop an optical digital storage device as a peripheral to existing computer systems. In the future they may package the storage devices with a minicomputer to produce a complete system. Though STC preferred not to give certain specifics above the physical properties of their disks, the planned capacity is 4 gigabytes on a single disk. They are planning to develop a multiple disk, multiple drive, jukebox-like device. Their goal is to produce an optical system with bit error rates equivalent to that currently obtainable on magnetic disk system. (Today's magnetic disks possess a bit error rates in the range of 10^{-12}.) Anticipated transfer rates will be the channel speeds of the mainframe computers to which these devices will be attached. (Currently, these rates are in the 3 megabyte range.) Initially, access times for these optical digital system will be somewhat slower than those of magnetic disk systems. The target date for availability of these optical storage devices is late 1984.

3.7 Omex

A different approach to optical storage technology is being taken by Omex, Inc. Instead of a DRAW disk system, Omex is developing a large digital document storage system with images recorded on five inch square glass slides. This system is targeted for users requiring a system having massive storage with

relatively slow access speeds. Initially, this system has been geared towards customers like real estate and insurance companies, with Omex providing either the complete system, including a computer, or just the peripheral storage device.

The media used is a modified bipolar structure with a polymeric dielectric underlayer acting as a thermal isolation layer on a glass substrate. Over the substrate is a modified tellurium layer, 300 Angstroms thick. A nitrogen atmosphere is sandwiched between the glass layers to prevent oxidation and ensure the desired archivability of 20 years. A 120-150 mW Argon gas laser and optics travel back and forth to read and write the data. At the present time, the system does not possess erasability. Each slide has a capacity of 360 megabytes of storage which translates into 6,000 to 10,000 pages of printed material using data compression techniques and a digital scanner. The storage device has a capacity of 2,048 slides with an armature capable of readying a slide for viewing while another is being read. They are working towards a bit error rate of 10^{-12}. The cost of a complete system is estimated to be several million dollars. Omex anticipates selling peripherals for approximately $1.8 million. The first of these systems has a planned delivery date of December 1982.

3.8 Burroughs

The Burroughs Corporation is currently developing an optical digital storage system, geared towards the storage of computer data. The system is a DRAW system. Burroughs is not currently working on erasability. The medium being used is a tri-layer structure on an aluminum substrate. The actual material to be used is proprietary information. The expected archival life is 10 years. The laser being used in the current prototype is a Helium-Neon gas laser. This type of laser will be used until future advances are made in diode laser technology. Eventually,

a switch to a diode laser is envisioned.

A single disk will possess the ability to hold two gigabytes of information. The first systems will be one disk systems with work progressing on a "library" system containing 100 disks. Burroughs is working towards a corrected bit error rate of 10^{-12}. The desired transfer rates are 1.5 Mbytes/sec. The target availability date is sometime in 1984. No price has been placed on the system at this time.

3.9 IBM

IBM has several ongoing activities related to the development of optical digital disk systems. Work is being carried out at the San Jose facility and at Yorktown Heights, New York. IBM sees the market for their products including mass data storage, office automation applications, tape replacement, information dissemination, as well as low-end computer data storage.

Major work is being carried out in the optimization of tellurium alloys and disk overcoats. There is also exploratory development activities underway associated with using thin films. Major work has been done at characterizing the data recorded on optical digital disks to get measurements of bit error rates. IBM is apparently focusing on using gallium arsenide laser technology and their systems will accept digital data from various input devices. They report that 2 to 4 gigabytes of data on a 12" disk is achievable but they also acknowledge that a multiple disk system will be required to meet the needs of mass data storage applications. They are apparently using track densities similar to those of optical videodisks which are in the 1.6 to 2.0 micron range. A corrected bit error rate of 10^{-12} is believed to be achievable as is a data transfer rate of .5 to 1.5 megabits per second using the gallium arsenide laser.

IBM believes that data transfer rates of 3 to 5 megabytes per second will be required for digital file-to-file transfers or high density digital acquisition devices but that would require using more than one gallium arsenide laser. They report that moving the optics can be done almost as quickly as moving the read heads on magnetic disks but it becomes an economic issue. Data access time could range from 200 milliseconds to 20 milliseconds depending on the cost of the system.

IBM apparently agrees with the rest of the community in setting a goal for a 10-year archival life for disk media but they are quick to point out that archival requirements are applications dependent. They are concerned about the effects of the acceleration factor involved in disk aging studies and have doubts that any digital optical media available today has an archival life of greater than 5 years in an unlimited environment at this time. Archival life, of course, is ultimately reflected in the bit error rates that can be tolerated. While IBM is actively engaged in exploratory research and prototype development, they do not appear to be near to making any optical digital system product announcements and it is believed they are at least several years away from marketing a product.

4. OPPORTUNITIES FOR EMPLOYING OPTICAL DISK SYSTEMS IN RADIOLOGY

As the review above points out, there are some optical disk systems which can be considered today for application in radiology-related projects and other systems that will be under development and testing for several years. Figure 2 summarizes several observations regarding the use of optical disk systems in light of the candidate applications areas noted in Section 1.

4.1 Education and Training

The most promising area of immediate application for optical

	Analog			Digital	
	CED	VHD*	Laser	Imaging Systems	Computer Data Storage
Education and Training	Yes (linear play only)	Yes	Yes	No	No
Video Display and Special Applications	No	Yes	Yes	Possible	Possible
Archival X-ray Storage	No	No	Possible	Yes	Yes
On-line Digital Radiography	No	No	No	No	Yes
Candidate Manufacturers	RCA Toshiba	JVC	Pioneer Magnavox TEAC (Thompson)	Toshiba Xerox Omex Optimum	RCA Philips STC Burroughs

*Announced but not yet introduced

Most Promising

FIGURE 2

CANDIDATE TECHNOLOGY APPLICATIONS

disk systems is in education and training. While all of the currently available optical videodisk systems could be used to augment education and training activities, the laser-based and VHD systems are most promising, due to their ability to directly and rapidly access any frame of information and to intermix color motion sequences as well as still-frames.

It has been demonstrated in several places, including The MITRE Corporation, that a microcomputer attached to in optical videodisk player can create a flexible information storage device.[9] This microcomputer-videodisk player combination can provide quick, easy access to information ranging from full motion sequences, to slow-motion sequences to still-frame displays. In addition, by adding an adjunct digital audio capability, it is possible to enhance the capabilities of the videodisk system even further. The digital audio can provide sound with slow-motion and still-frame video that is normally not available from the videodisk player. It also allows several different audio tracks to be attached to the same video sequence. This allows a video sequence to be made relevant to different audiences by providing different explanations. For example, the same video sequence on CAT scanners may be presented to laymen, pre-med students, nurses, technicians and advanced medical students by providing different audio descriptions geared to the sophistication of the audience.

The major drawback of the existing optical videodisk systems, from the radiologist's point of view, is the lack of adequate picture resolution for the storage of radiographs. The picture quality of the frames on the videodisk is restricted by the adherence of the disks to NTSC television standards. Under the NTSC standard, each frame is made up of 525 scan lines. It has been shown that the resultant picture quality is not adequate

for the resolution requirements of radiography. As an archival medium, however, the optical videodisk appears promising. The shelf life of the existing optical analog videodisk is projected at more than 10 years.

Though the optical videodisk is not currently capable of storing radiographs, it can be successfully used within the radiology community. Videodisk players, when controlled by an intelligent front-end, are a flexible training and education device. Using its ability to provide full motion, slow motion and stop action sequence, with augmented digital audio, the videodisk can be an effective presenter of educational material. Videodisks can be used in the training of all levels of personnel in radiology and could even be used to familiarize patients with upcoming procedures.

Analog optical videodisk system are also finding their way into computer-assisted instruction (CAI) systems. The TICCIT system, marketed by the Hazeltine Corporation, has recently incorporated an analog videodisk player to present graphic displays and motion sequences during a training or educational setting. While CAI systems such as TICCIT are considerably more sophisticated and costly than a stand-alone intelligent videodisk system, there are exciting possibilities for use of CAI systems equipped with videodisk players, in university and hospital settings.[10]

4.2 Special Video Display Applications

One of the strengths of the optical videodisk systems available today are the large number of high quality video images that can be stored and rapidly retrieved. This makes the analog videodisk a prime candidate for providing video displays for use in such applications as automated radiology reporting systems. The videodisk player can easily be incorporated into a computer-

based system which would display selected anatomical areas, radiological terms and other graphic presentations. The current systems are still limited to the resolution achievable on an NTSC television screen but displays could easily be designed to accommodate the constraints of the standard TV systems.

The radiology lexicon incorporated as a part of the Siemen's automated radiology reporting system is an example of where existing analog videodisk systems might be employed. Preliminary investigations indicate that reformatting of terms and displays would be required but the speed of the system could potentially make up for using more displays.

As noted in the Figure 2, the optical digital systems being developed are also candidates for storing video displays and graphics and these systems will be able to achieve better image quality using high resolution monitors and graphics displays. However, the cost of these systems will be high for some time, and it is unlikely that these systems will be used for video display devices in the near future.

4.3 Archival Storage of X-Rays

Possibly one of the most exciting applications of optical disk systems is in the archival storage of X-rays. MITRE had an analog videodisk mastered with X-rays taken from the Bureau of Radiological Health's teaching file and found the display resolution inadequate for diagnostic purposes. While the videodisk file could be used today as a pictorial index to radiographs, other optical storage approaches are needed.

The use of an analog laser-based system to store digitally encoded images as discussed in Section 2.3 has possibilities here. By scanning an X-ray and converting it into digital form

and then storing it on an analog optical disk, there is the potential for capitalizing on the high storage density and low cost of the existing videodisk player and, at the same time, achieving high resolution output. Converting the NTSC video frame containing digital information back into digital form permits the display of higher resolution images on a high resolution monitor. While there is still the problem of mastering a disk and the attendant costs, roughly 1,000 images (1024 x 1024 x 8 bits) could potentially be stored on one side of a disk with no data compression and perhaps as many as 2,500 images with a 2:1 digital data compression ratio. With disk media costs at $10 per disk, this could mean a media cost per image of $0.004 to $0.01 per image. While this ignores the mastering costs associated with production of the initial disk, wide distribution of a teaching file of radiographs could make the whole approach cost effective, particularly when using the laser-based analog players on the market today.

The system that will be the workhorse for archival storage, however, will be the optical digital disk systems under development today. These systems will have the capability to record an X-ray locally with no need for sending away a type of film to be mastered on a disk. High resolution output devices will be available so that display resolutions of 1024 x 1024 will be easily achievable. The problem with these systems at the present time is availability and cost. RCA and Philips are reporting systems that have the specifications necessary to digitally store images with significant information content for high quality diagnostic accuracy. Pilot projects are planned by the Bureau of Radiological Health and MITRE and it is anticipated that feasibility will soon be demonstrated. This, however, does not mean that we can expect optical digital disk systems to rapidly proliferate throughout hospitals and university radiology departments. It is important that optical digital disk manufac-

turers team with major computer companies and develop optical systems which can achieve the accuracy needed by the computer data storage industry to provide the necessary economic incentives for system development and ultimately to lower system costs.

4.4 On-Line Digital Radiology

The most demanding application for optical digital disk systems will be the support of advanced digital radiograph systems. These systems will use no film and will produce a high density image in the form of millions of bits of digital data. For this application three challenges face optical disk developers.

The first is handling high data transfer rates. It will be necessary to accurately capture and record high volumes of digital data and the data transfer rates from the image acquisition device will be high. Philips reports the capability to transfer 24 megabits/sec while RCA's systems potentially have data transfer rates of 50-200 megabits/sec for single channel, single disk systems. Data rates such as these will be needed for high quality digital imaging systems.

The second challenge is to develop a system which has the requisite storage capacity for digital radiographs. While there is still no consensus on the resolution required for an electronic replacement for films, it is fair to say that optical digital disk data storage devices will need to handle a minimum of 10^{12} bits to be of use for this application. These systems will remain expensive for sometime and it will be necessary to store large quantities of data to make the systems cost effective in operational use.

The final challenge is the archival properties of the disk.

Research is being carried out by Philips, Kodak, Drexler, Corning, 3M and Energy Conversion Devices to develop a stable and inexpensive disk coating with good archival properties. Approaches include using coatings of thin metal film alloys in hermetically sealed disks, using dye-based polymers as a wavelength sensitive absorber, using heat sensitive amorphous semiconductors and using halide-based thin films with polarizing light sources.[11] All of this work is targeted at developing media which can guarantee at least a 10-year archival life, allowing for more accurate reading and writing of digital data, achieving higher storage densities and perhaps erasability. Digital radiology will require demanding archival properties for any optical disk system and this is an area of active research by media developers today.

As indicated in Figure 2, it is the high-end systems being developed for use as computer system peripheral storage devices that are likely to be applied to this area of radiology. These systems will have the accuracy (i.e., bit error rates $<10^{-9}$), the speed (i.e., data transfer rates >50 megabits/sec and access times of <500 millisecond) and the archival properties (i.e., disk life > 10 years) necessary to meet the demanding environment of on-line digital radiology.

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[10] Personal conversation between William McCloskey and Harry Strong.

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COMPUTER MONITORING OF CLINICAL STUDIES

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INTRODUCTION

The Philadelphia office of the American College of Radiology houses the headquarters and statistical unit of the Radiation Therapy Oncology Group (RTOG) and the Patterns of Care Study (PCS). These organizations conduct ongoing studies of the nature and patterns of cancer care in the United States. RTOG is a Clinical Cooperative Group supported by a grant from the National Cancer Institute -- Division of Resources, Centers and Community Activities; PCS is also funded by the National Cancer Institute.

The function of the computer center at the Philadelphia office is to serve the needs of data collection, quality control and data analysis in the clinical cooperative group setting. This paper purports to describe the software system that has been developed in support of the data analysis effort. Before proceeding, I think it would be beneficial to outline some of the singular attributes of the kind of medical data we are handling.

MEDICAL DATA COLLECTION

Medical data collection in a clinical cooperative setting differs intrinsically from most other types of data collection; here, variability is the rule rather than the exception. To illustrate:

- The number and type of forms required on individual studies varies widely. (The number of forms may range anywhere from one to about sixty.)
- The data items on any particular form type may vary within a study.
- The idea of "what's important" may vary or evolve as the study and the analysis progress.

Although flexibility is the keynote in forms and data definition there are notable and predictable similarities between studies:

- Each patient has a treatment option, date treatment commenced, and status (alive, dead, or lost to follow-up).
- Medical data is quantifiable in most cases and able to be coded.
- Each cancer has an associated body location. Uniform terminology to specify such locations is useful in analysis across study boundaries.

With over 30 active studies and well over 4000 forms being entered per month, our challenge has been to streamline data collection and analysis without costly and time consuming programming for each study.

SYSTEM DESIGN CONSIDERATIONS

At the outset, some 5 years ago when RTOG was considering design approaches to the programming system, we looked at the "80 column card" approach which was widely used. Many features of the system subsequently designed for RTOG were in response to shortcomings of card or card image entry techniques. For example, with a card approach:

- Data often must be transcribed from the original form to a data entry form before it is entered onto a computer.
- Data checking can be cumbersome.
- Blank fields can cause special problems, and fields are often blank in clinical responses.
- Schemas or formal data dictionaries are not integral to data input. As a result, subsequent processing of the data requires custom formatting in a computer language by someone with programming skills.

- Certain operations common to clinical trials analysis, such as linking together all forms relating to a particular patient or hospital, become formidable data processing chores.

RTOG further determined that an efficient data entry operation would be greatly enhanced by an administrative and quality control system built into the data entry operation. Drawing on the experience of Stanford, we designed our system to take into account a basic feature of the data, i.e., it represents medical histories.

The main attributes of the RTOG system design are:

- All data entry and change is interactive.
- Data is entered directly from the medical forms themselves.
- Medical form descriptions used for data entry and retrieval are entered by non-programmers using an interactive query approach.
- Data checking takes place at data entry time. This verification depends on checking the data against limits and valid codes entered when the form was originally specified through the forms definition program.
- All medical data pertaining to a particular study resides on a single file.
- All records belonging to a particular patient are physically linked together for ease of analysis.
- All patients for a single institution are likewise linked together.
- The procedure for creating a data analysis file requires no programming.

- Administrative controls are built into the data entry system. For example, as each clinical case is initiated in any study the computer generates a calendar of future form submission requirements. As case reports are received from submitting institutions, they are logged by the computer. Memos concerning overdue forms are automatically generated and sent to contributing institutions. Periodic reports are also sent to institutions informing them of their participation statistics, and alerting them to upcoming forms submission requirements for each open case.

MEDICAL FORM DEFINITION

Turning now to our systems provisions for data analysis, we see that the point of departure for structuring an analysis is the forms definition system used to describe the data set up. Each form has a schema associated with it. This schema, as has been noted above, is entered interactively by a medical data specialist, at the time the study is set up, specifying parameters such as:

- Form parameters
  1. Name of form (type and study number)
  2. Descriptive name
  3. Number of questions
- Question parameters
  1. Question number and name
  2. Type of data (character, integer, date, etc.)
  3. Special processing attributes, if any
  4. High and low limits for validity checking
  5. Units associated with data item (centimeters, rads, etc.)

6. Default value, if any
7. Test value and next question number for automatic question branching
8. Code table reference, if any. (For each code table reference additional questions must be answered, i.e., type of code; legal code values and their descriptions.)

It should be noted that a good deal of care goes into these form definitions. When the interactive forms definition for any entire study has been completed, a review and checking operation commences. Representatives both from the data management and statistical units review the reports generated by the computer; these reports describe how incoming medical data will be processed and verified according to the medical form description parameters already specified. When agreement is reached, data entry can begin.

DATA ENTRY AND RETRIEVAL

All data input for a given study is then entirely controlled by this "schema" I have described. A generalized input program feeds our input operators a prompt for each question or item on the form to be entered. The program waits for a response, and then operates on the response, checking and interpreting it according to the schema and its associated code tables. If interpretation occurs, the program will feed back or "echo" its interpretation of the response. If the response does not fall within the limits defined by the schema, an error message will appear, along with an audible "beep" from the terminal. This process continues for all questions on the form, after which the data input program performs an on-line update of the study master file.

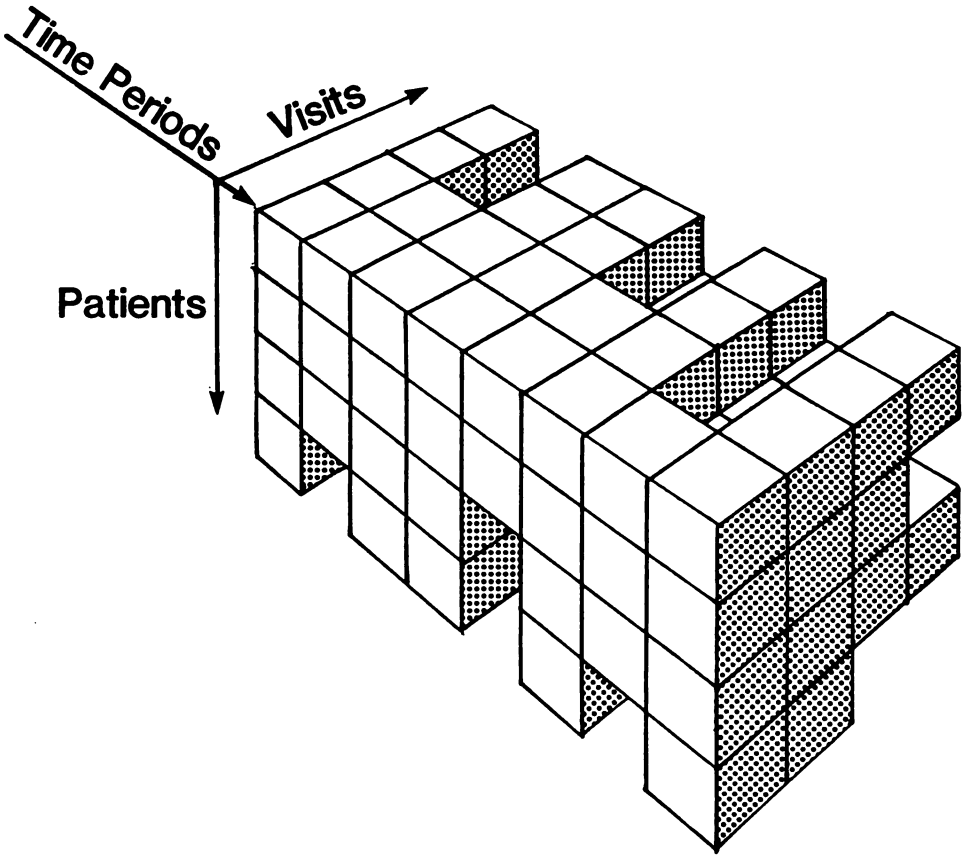


Fig. 1. Structure of Medical Data

All records thus entered are stored and indexed by institution and study entry date. Case records for a given institution are connected by physical pointers. All form occurrences for a given patient are similarly connected. (See Figure 1.) Thus, for example, it is possible to instantaneously reconstruct a case history from the forms submitted on a particular patient, and subsequently the terminology "time-oriented (history-oriented) data base system." To complete the picture, it should be noted that the "medical records" are actually composed of three types of data:

- Patient identification data
- Pure medical data
- Physical linkage data

This inclusion of physical linkage data both distinguishes our system from the "card image" system mentioned earlier and provides the underlying reason for our system's offering instantaneous response to most types of queries.

MEDICAL DATA ANALYSIS

At last we come to the primary subject of this paper, which is how our computer system facilitates the analysis of medical data. It is ironic that at this point, while our data is in a most convenient format for data entry, storage and retrieval, many of the standard statistical packages, for historical reasons, require that the data be in "80 column card image" format. However, as you might surmise, this is not really a problem.

With the system we have developed, the first step in an analysis requires that a statistician or medical analyst request a summary of the schemas for all forms of interest on the study to be analyzed. After reviewing the computer generated medical form dictionaries for that study, the analyst makes up a command file capable of extracting up to 2,000 specific pieces of information on each patient. Running the extraction program creates an entirely new and consolidated version of the medical data file for statistical analysis. The main attributes of this file are:

- There is one record per patient.
- Each record contains all the information deemed requisite to the particular analysis.
- The sequence of medical data in each record follows the order requested by the analyst. In other words, the analyst is free to design a

"customized" medical record according to his own information requirements.

- The file is a "snapshot" of all the relevant data on a study at a given time. Once the "snapshot" is taken, data entry can continue.

The computer automatically generates a new dictionary or template for this master analysis file by referencing the study's form specific schemas. This dictionary features an ordered description of all the data contained in the analysis file.

The final step in preparing the data for statistical use is the sub-extraction and transformation phase. In this phase, the analyst, using English-like commands, extracts data from the master analysis file and restructures it to make smaller "card image" files suitable for input into the standard statistical routines. The options currently available for transformations and combinations are:

- SUM -- The sum of any number of data elements. (For example, this might be especially useful in totaling the rads received by a patient when the data has come in on separate treatment forms.)
- DIFFERENCE -- The difference between two data elements. (For example, this would be useful in determining the time span between two events.)
- MINIMUM -- The minimum of any number of data elements
- MAXIMUM -- The maximum of any number of data elements
- AVERAGE -- The average of any number of data elements
- IF -- If any data element or group of elements contains a value between user supplied limits, then the user is able to create additional

variables. (For example, if the IF is satisfied, the user can create a new variable equal to a constant or another variable.)

There are quite a number of advantages to this two phase process in preparing medical data for analysis. The primary extraction provides a comprehensive yet easily understood master data set; the sub-extractions that operate on the master data set offer great flexibility. A summary of attractive features would include the following points:

- o No programming is necessary to prepare data for analysis.
- o It is easy to consolidate information from various medical forms, received at different times, and from the administrative data base as well, into a single comprehensive data set, organized specifically for analysis purposes.
- o The extraction captures a "freeze-frame" or "snapshot" of the data at a given time. This allows data entry to continue while fixing an analytical data set; the set can still be rechecked if questions arise later with respect to input to the analysis.
- o In that the extraction is broken down into two phases, a useful division of work also occurs. Namely, forms can first be reviewed and consideration taken of how the available data can be used. The second phase leaves the analyst free to concentrate on intensive theorizing, hypothesis formulation and statistical analysis.
- o The system is self-documenting; it facilitates analytical updating since the analyst can later re-create the procedures by simply applying the command files for extraction and sub-extraction to the updated data files. This is particularly convenient in studies that need periodic

checking for toxicities, etc.

- By eliminating custom programming for each study we save costly programmer time. Perhaps more importantly, however, we prevent opportunities for errors that may not be discovered until much effort has been expended or, worse, errors that remain hidden.
- By putting the analysis in the hands of the statistician or medical analyst we avoid a host of communication and personnel problems. The effort needed to master the syntax of the extraction command files is minimal; thus the analyst becomes fully responsible for his or her output.

CONCLUSION

In conclusion, I would just like to say that from my point of view as a programmer, a system like this is extremely efficient as well as gratifying. It allows the programming staff to put effort into areas with a high payoff -- such as making the general extraction programs more flexible and functional -- and enables us to avoid stressful last minute, "need it yesterday" custom programming for each individual study and study analyst.

TELERADIOLOGY: A FIELD TRIAL

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Introduction

The lack of timely access to radiologists' interpretations of images is a major problem for millions of Americans living in rural areas and for members of the Armed Forces and their dependents stationed at many military bases. Common approaches to overcoming the problem are "circuit riding" visits by radiologists to rural clinics or hospitals and the shipment of radiographs to medical centers. One military solution is to contract with civilian radiologists to provide professional services at small bases. Increasing attention is being focused on the feasibility of using teleradiology to transmit radiographic images in digital form over telephone lines to consulting radiologists (Fig. 1).

Several federal and private agencies are cooperating in the development and evaluation of teleradiology systems. These include the Public Health Service, Department of Defense and the MITRE Corporation. Recently, a microcomputer-based system was developed to overcome the technical and operational shortcomings noted in an earlier evaluation of a slow-scan television system (1). These improvements concerned image quality, transmission accuracy, processing, storage and retrieval.

The laboratory evaluation of the microcomputer-based system was reported at the 1980 meeting of RSNA and published in Radiology in August 1981 (2). The evaluation showed that when compared with the diagnostic accuracy associated with films, interpretations based upon the video mode were less accurate. Nevertheless, the level of image quality demonstrated

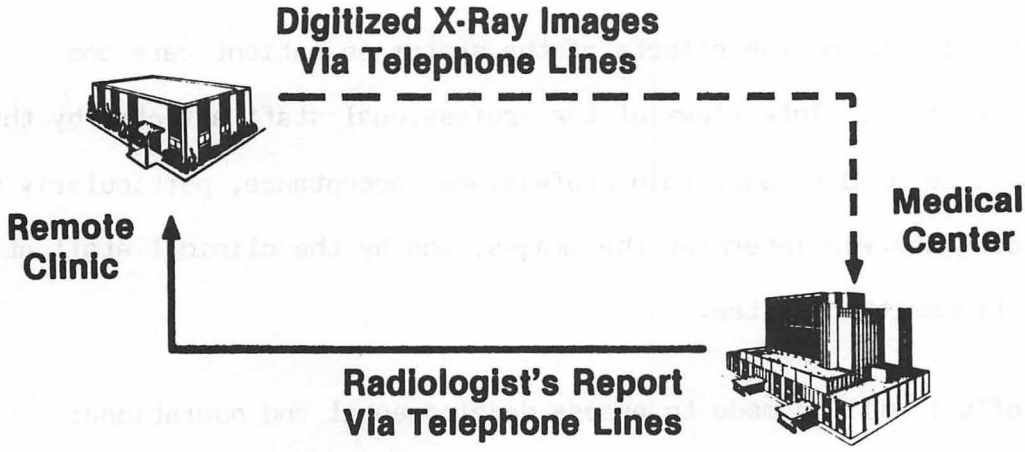


Figure 1. Flow of X-ray Images and Radiologists Reports

by the microcomputer-based system was considered satisfactory for more timely service to remote communities and, in the judgement of the participants, further evaluation in a realistic environment was warranted. Therefore, after 18 months of planning, a field trial began in February 1982.

Objectives

The field trial objectives include separate evaluations of the technical, clinical, human and economic considerations associated with this system. The technical feasibility of the components of the system and their linkages are being thoroughly tested in routine use over a six-month period. Specific hardware and software difficulties are being documented.

The clinical effectiveness is being examined in two ways; first by measuring elapsed times between functions in the radiology request/report cycle before and after the system became operational; second, and the participants, particularly attending physicians, will be questioned

to obtain opinions on the effects of the system on patient care and clinical practice. Interviews of the professional staff affected by the system will be used to ascertain professional acceptance, particularly by the radiologists who interpret the images, and by the clinical staff at the four transmitting sites.

An effort will be made to assess developmental and operational costs within the constraints of the field trial setting. Finally, the participants in the field trial will develop recommendations for the Public Health Service and the Department of Defense regarding the future use of teleradiology as an operational system. These recommendations are scheduled to be published in September 1982.

Site Selection

The primary concern influencing the selection of appropriate sites for the field trial was the identification of medical care facilities that performed radiographic examinations, but did not have a full-time radiologist on the staff to interpret the findings. In view of the interests of the sponsoring agencies, it was also highly desirable to have representation from the Public Health Service, and each of the armed services of the Department of Defense. After considering several areas of the country, the Washington Metropolitan Area was selected with Malcolm Grow Medical Center at Andrews Air Force Base in Maryland, serving as the central interpretation facility for four remote clinics. These clinics include: Fort Detrick at Frederick, Maryland; Bolling Air Force Base in Washington, D.C.; Patuxent Naval Air Test Center in southern

Maryland; and, the Central Virginia Community Health Center in New Canton, Virginia.

Professional radiology services provided at these sites vary. The Fort Detrick Clinic is served biweekly with visits of a member or resident of the Walter Reed Army Medical Center staff. The Bolling Air Force Base Clinic films are interpreted at Malcolm Grow Medical Center after delivery each day. Service is provided to Patuxent by the National Naval Medical Center in Bethesda, Maryland, through the daily delivery of films alternating every other week with the visit of a radiologist or resident for three days of fluoroscopy and film reading. Each day the Central Virginia Clinic sends its films to the Radiology Department at the University of Virginia in Charlottesville for interpretation.

System Components

An identical hardware configuration has been installed at each of the four transmitting clinics to provide for digitizing and transmitting all radiographic images produced during the period of the field trial (Fig. 2). Each has a video camera/ light box input arrangement for scanning radiographs, a frame memory for digitizing and storing the images, a CRT terminal for inputting patient information, a 200 megabyte disk, and a control processor for interfacing the frame memory to the disk and for reading out cases from the disk through the communications hardware (Fig. 3). Cases are automatically transmitted from the clinics to the receiving center over dedicated 9600 baud telephone lines by constantly polling the disks at each site and transmitting the cases on a

TELERADIOLOGY
TRANSMITTING SITE

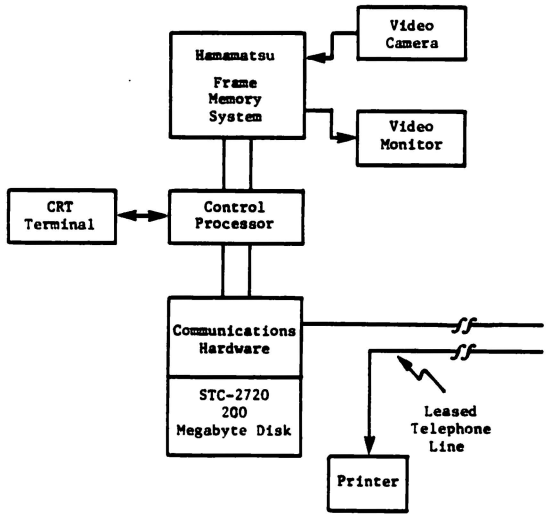


Figure 2. Teleradiology Transmitting Site

first-in/first-out basis. The processor automatically assigns a unique number to each case and controls transmission without any delay being evident to the technologists.

At the receiving center the digitized images and patient information are stored on disks identical to those at each of the four transmitting sites (Fig. 4). There is a receiving disk at the central location for each of the four transmitting sites. During interpretation sessions, the radiologist calls for cases from the disks using a keyboard attached to the CRT terminal. Displays are generated on three video monitors after image processing on the COMTAL system. The radiologist controls the display functions through keyboard selections on the CRT terminal which also presents patient information and data about the number and type of images associated with each case.

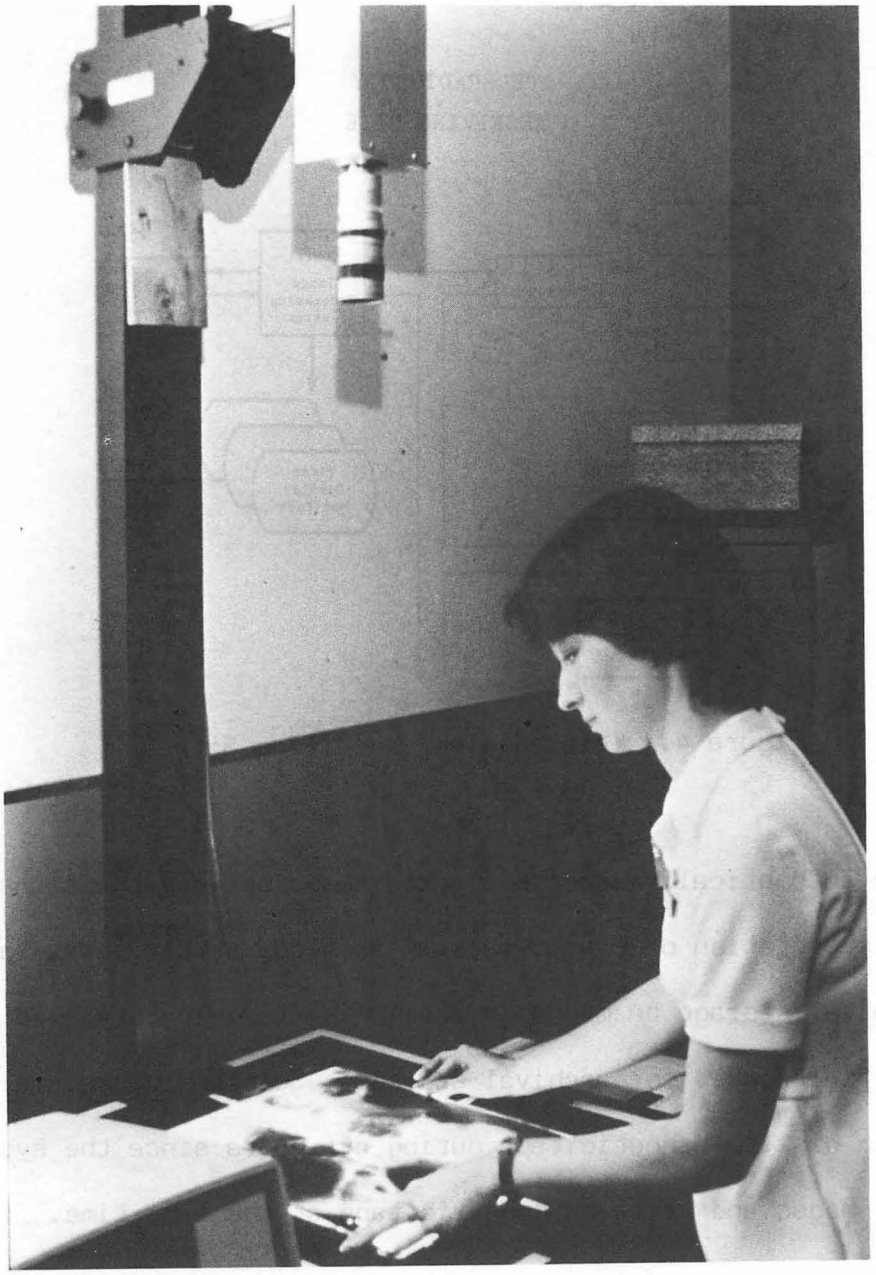


Figure 3. Technician Digitizing An X-ray Film

During routine video reading sessions, the cases are presented to the radiologist on a first-in/first-out basis. The radiologist has the option of switching to a priority mode, if required for immediate consultation with physicians at the transmitting sites.

TELERADIOLOGY
RECEIVING SITE

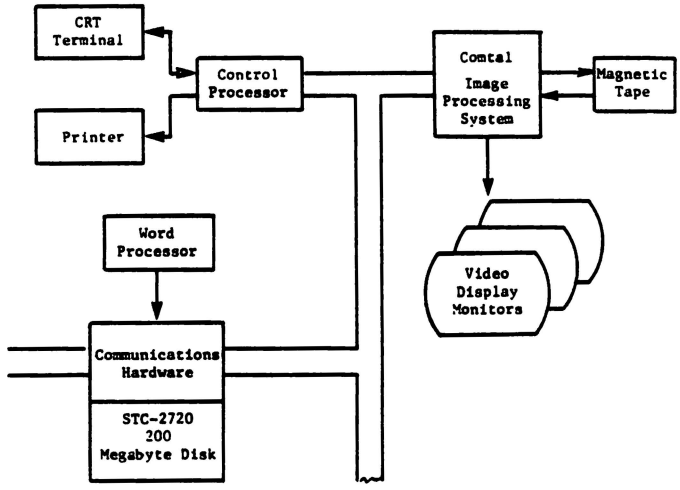


Figure 4. Teleradiology Receiving Site

The system automatically records elapsed times between the transmittal, receipt and interpretation of cases, as well as flags sample cases for subsequent archival storage on magnetic tape. The radiologists also may select "interesting" cases for archival storage. Selected cases are transferred from disk to magnetic tape during off hours since the system cannot process images and write on magnetic tape at the same time.

Radiologist reports are transcribed on a word processor from audio tape cassettes and are stored on a diskette (Fig. 5). After a report has been approved by the dictating radiologist, it is transmitted over the 9600 baud telephone line to the site where the x-ray examination was performed. A printer at each site produces multiple copies of each report for distribution to the attending physician and patient's chart.

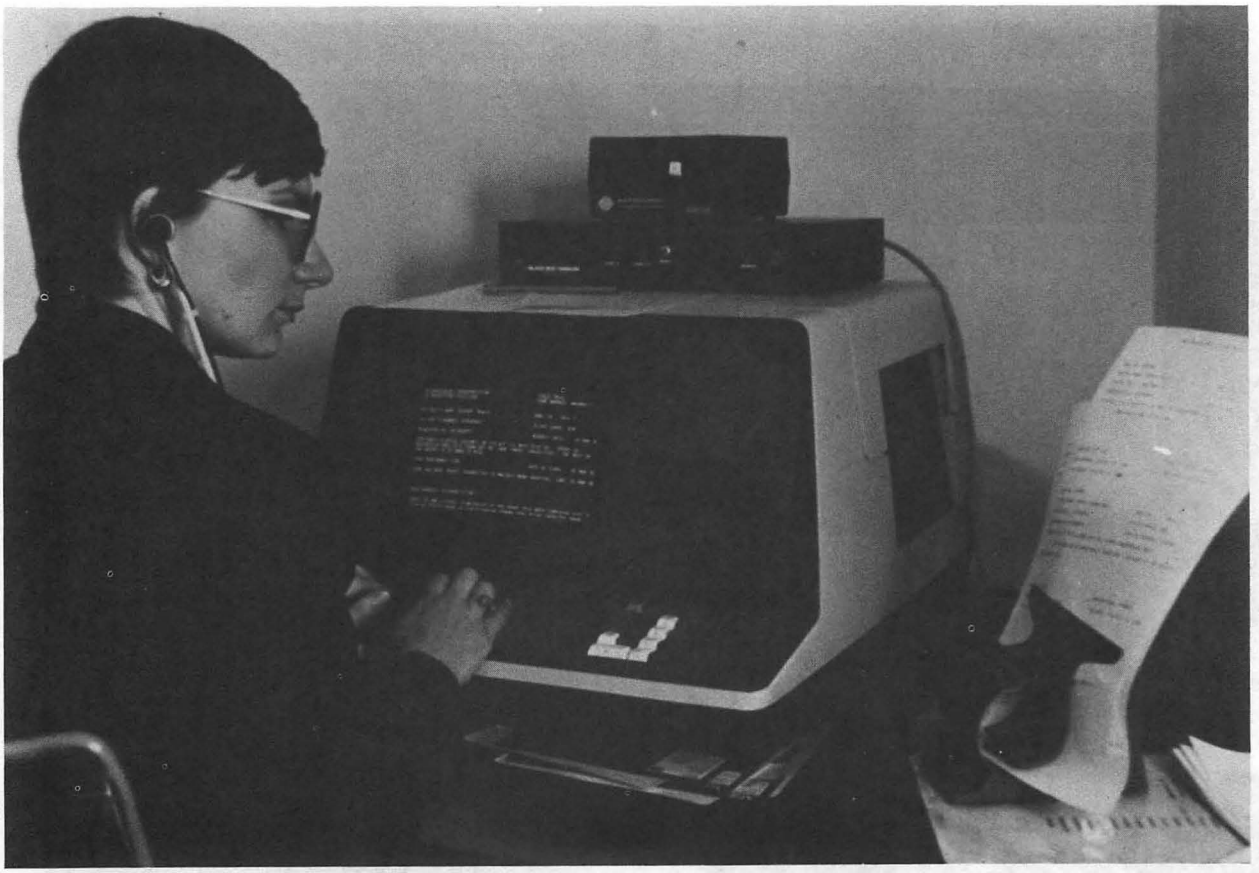


Figure 5. Transcriptionist Preparing Radiologist Report For Transmission To Remote Site

Design of the Field Trial

The basic design of the field trial provides for continuation of the existing radiology services without interruption, i.e., all films are interpreted just as if the field trial were not underway. A copy of the film interpretation is provided to the field trial project staff for comparison with the video report.

Thirty radiologists were recruited to interpret the digitized images on the video displays at Malcolm Grow Medical Center (Fig. 6). Twelve civilians from the Johns Hopkins Hospital, University of Virginia,

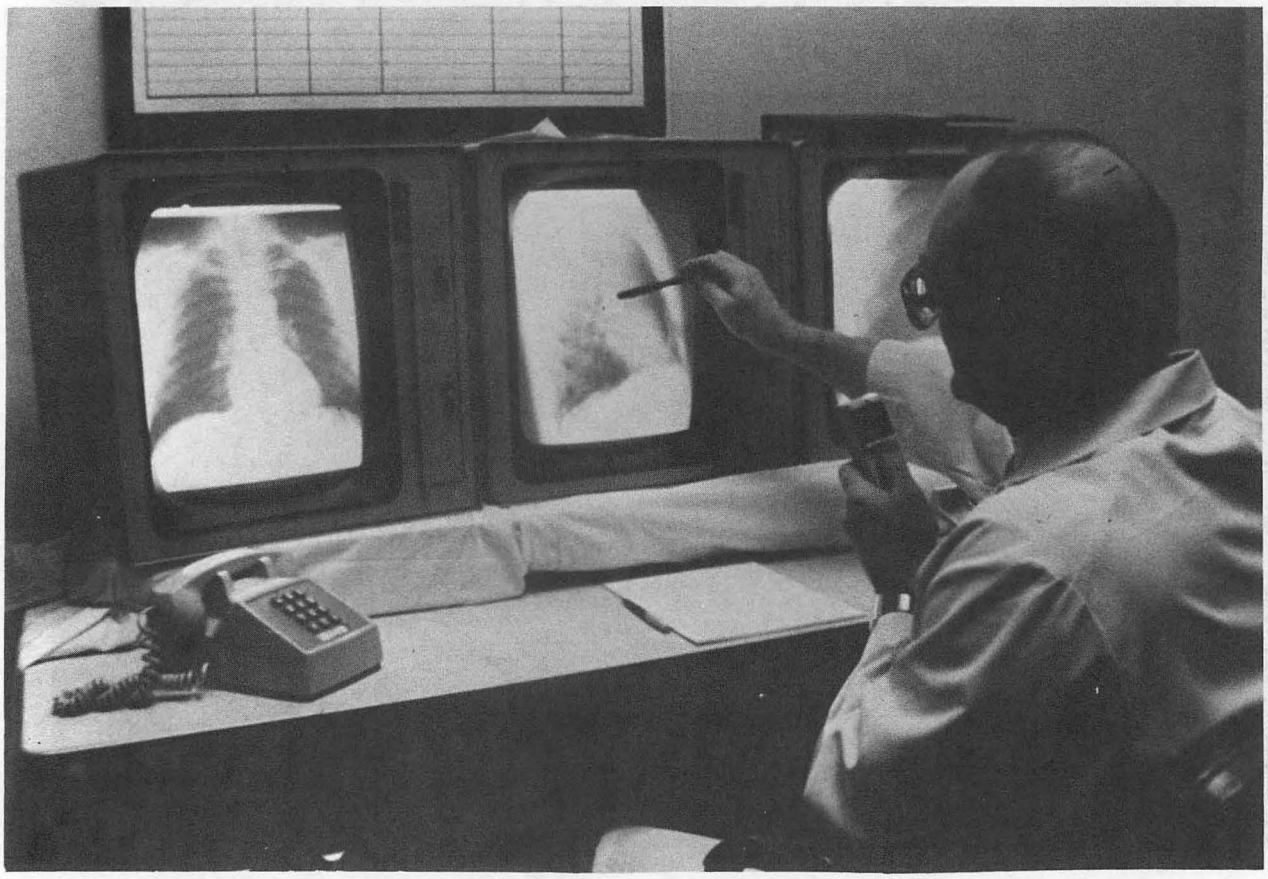


Figure 6. Radiologist Interpreting Video Images On Three Displays

and George Washington University, and eighteen Army, Navy, and Air Force radiologists affiliated with the Uniformed Services University, School of Medicine are participating. With an estimated eighty cases per day, two radiologists share the workload, interpreting approximately 40 cases each during the morning and afternoon sessions at Malcolm Grow Medical Center. Video reports are transcribed on a word processor and are transmitted immediately to the originating site after review by the dictating radiologist. Each of the video reports carries a notation indicating that it is based upon an experimental system and that the usual film report will follow.

In addition to comparing the findings and impressions on the video and film reports for each case, a separate panel of three radiologists meets weekly to review a representative sample of the cases to establish a baseline for subsequent statistical analysis including the development of ROC curves. This same panel also reviews all cases where a discrepancy occurred between the video and film reports.

Archive For Future Research

One of the important by-products of the field trial is the establishment of a permanent reference file of representative cases for future investigations. This file will be maintained by the Bureau of Radiological Health and made available to researchers and scientists interested in furthering the development of digital radiology. For each selected case the archive will contain the digitized images, the initial video interpretation, high quality copies of the original x-ray films, the initial film interpretation, and the panel reports on the video images and the films. It is anticipated that approximately 500 cases representing a random sample of those included in the field trial will be retained in the archive. Cases designated as "interesting" by the participating radiologists and those where there was a discrepancy between the video and film reports will also be retained.

One proposed use of the archive is to compare the "accuracy" of interpretations of the same cases at a higher level of resolution, e.g., 1024 X 1024 pixels X 8 bits, with those obtained in the field trial at 512 X 512 X 8. Such a study could effectively utilize the large body of available information in an effort to contribute to

answering the question of appropriate resolution for future interpretation of digitized radiographic images. The archive may also be used to develop standards and specifications for formatting digitized images, converting x-ray images on film to digits in an electronic system, and for providing appropriate display equipment to be used in the interpretation of such images.

Disclaimer

The opinions and assertions contained within this article are those of the authors alone, and do not necessarily represent those of the United States Army, Navy, Air Force or Department of Defense.

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COMPUTER-AUTOMATED SCHEDULING PROGRAM FOR FACULTY ACTIVITY/DUTY ROSTER

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That aspect which best characterizes the changes which have taken place in contemporary radiology is subspecialization resulting from a proliferation of technology. No other specialty in medicine is so obviously and thoroughly dependent upon the forefront of advanced technology as is radiology. The computer in radiology seems to combine the traditional visual element intrinsic to the specialty with the essentially logical methodology which computers represent.

In applying computer technology to scheduling it is useful to consider that, in all systems of work, efficiency is a primary goal and is, to a major degree, dependent on distribution of tasks among those who are best suited to perform them. The problem of scheduling in general may be considered as a matter of allocation of finite resources (professional faculty) within a rigid time/efficiency dependent framework.

The obvious usual solution to the problemn is creation of a work/duty/activity schedule. In small departments this process may consist of simple analog devices, such as plastic or wood signs or indicators ["Gone fishing", "I'm off today, you're on duty"]. However, in large systems with ever increasing patient loads, and those which must incorporate a variety of professional activities (such as teaching hospitals which require research, teaching, and administrative as well as clinical efforts), a substantially more sophisticated method is essential.

In developing a schedule there is a need to incorporate enough flexibility to respond to the variable and complex needs of a department. In addition, the schedule must consider the skills, time, and patience of the scheduler. Because that human element is always involved and is typified in the frequent trading of assignments--and continual argument over assignments ["But you KNOW I can't do IVP's on Thursdays"]--keeping

the record straight on a cumulative basis is taxing. Scheduling is a difficult task in its own right when done by the traditional manual method, but is virtually impossible using that method in large departments.

Metropolitan General Hospital is a 1000 bed acute general hospital and is a teaching hospital of Case Western Reserve University School of Medicine. There are over 200 fulltime staff/faculty. Within the Department of Radiology there are 15 fulltime radiologists. Over 120,000 examinations in Radiology were performed during 1981 which incorporates an annual growth rate of about 12% per year.

Because of the complexity of scheduling for such a large institution and patient load, we undertook to design a computerized scheduling system which intended to achieve these goals:

1. Ease of operation by personnel unsophisticated or untrained in computer operation (the average radiologist or his secretary).
2. Accommodation of existing departmental practices and customs such that computer schedules conform to the current manual system as closely as possible, and perhaps be interchangeable. (Avoid changes in work patterns)
3. Provision of operational discretion: automated operation with manual override when desired.
4. Minimal amount of outside reference for comprehension, obtained through use of simple, "menu"- type selection profiles.
5. Provision for academic activities during a daily schedule (teaching, research, meetings, CME, etc.).

COMPUTER SCHEDULE DESIGN

Our program, written in Fortran, is operational on the time-shared Digital Equipment DEC-20 of Case Western Reserve University. The program

design parameters provide: 1) a schedule for up to 275 future days for up to 73 participants; 2) identification of 11 discrete activity categories per day; 3) six of the 11 categories are further subdivided into morning and afternoon categories; and 4) recognition of certain constraints.

Operationally, the chief design feature of the program is a weighting process where each participant is assigned, for each activity, a numerical rating on a scale, 0 to 99, that determines eligibility for participation in that activity. For example, "0" = never schedule for that activity; "99" = always schedule for that activity.

The program creates the schedule a day at a time in sequential fashion, based on a combination of the numerical rating, prior assignments, and constraints selected. The last may include vacations, meetings, and conferences in the format, "Do not schedule..." in morning, afternoon, and evening partitions each day, and also in groupings by whole days.

The method by which this is achieved programmatically is as follows: For each day, and for each activity category, the program scans through the numerical rating of all participants. After eliminating those where a conflict might exist (e.g. already scheduled for another activity category, vacation, etc.), the program selects the individual with the highest numerical rating to perform the activity under consideration. At that point, the numerical rating value of the selected individual is returned to its original value, which is equal to the eligibility rating originally assigned for this activity (or is held at its original value, if this is the first assignment). At the same time, the numerical rating of all other participants, eligible for the activity but not assigned, is incremented by 1. In this way they will participate in a higher liklihood

SELECT "0" To LIST schedule.(or Mo,Day,X)

"1" To CONSULT or MODIFY a day's schedule

"2" To UPDATE schedules

"3" To enter a NEW name.

"4" To CONSULT or MODIFY a Drs. availability.(or Nr.)

"5" To LIST Drs. availability

"6" To LIST Drs. UNavailability

"7" To LIST a summary of Drs.past involvment

"9" To stop the program

SELECTION :

Fig. 1 Main Menu. This comprises a listing of all program functions available. To commence operation the desired function is selected from the nine choices listed, which calls up the corresponding screen on the display.

of being selected with each subsequent iteration of the process.

SYSTEM OPERATION

The main menu (Fig. 1) lists the range of functions available. Operation of the system proceeds as follows:

In the start-up phase, the system parameters are set in place. These consist of:

a) Activity categories. Eleven are included in the system design (Fig. 2) and are not subject to change without program modification. These include fluoroscopy, alternator 5 (film reading), wet readings (a.m. and p.m.), conference, late stay, Sunny Acres (outside hospital), continuing medical education, ultrasound, CT scanning, nuclear medicine and angiography.

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Mo.Day --		Fluo	Alt5	amWRpm	Conf	Lat	S.A	CME	US	CT	Nm	Ang
3.31	We	31-35	30	34/30	38	30	**	35- 0- 0	32/32	40/40	36/36	29/29
4. 1	Th	39-34	31	30/35	34	35	**	31-30- 0	32/32	40/40	36/36	29/29
4. 2	Fr	34-30	39	31/39	31	36	35	32-40-29	32/ 0	40/ 0	36/36	29/ 0
4. 3	Sa	40-**	**	**/**	**	**	**	**-**-**	**/**	**/**	**/**	**/**
4. 5	Mo	30-32	34	39/32	38	30	35	34-39- 0	29/29	40/40	36/36	37/37
4. 6	Tu	39-35	30	34/31	34	29	**	35-30- 0	29/29	40/40	36/36	37/37
4. 7	We	34-31	32	30/35	32	32	**	36-31- 0	29/29	40/40	36/30	37/37
4. 8	Th	35-32	31	39/34	39	39	**	32-40- 0	29/29	40/30	36/36	37/37
4. 9	Fr	31-30	35	32/34	38	31	35	36-29- 0	29/32	40/40	36/30	37/37
4.10	Sa	30-**	**	**/**	**	**	**	**-**-**	**/**	**/**	**/**	**/**
4.12	Mo	41-39	34	35/32	38	40	35	34-39- 0	30/30	40/40	36/36	37/37
4.13	Tu	34-32	41	39/31	38	38	**	41-35- 0	30/30	40/40	36/36	37/37
4.14	We	35-39	32	41/34	41	36	**	30-31- 0	30/32	40/40	36/36	37/37
4.15	Th	41-39	35	34/35	34	34	**	32- 0- 0	32/30	40/40	36/36	37/37
4.16	Fr	34-32	39	35/ 0	38	41	35	40-36- 0	30/32	40/30	36/41	37/37
4.17	Sa	32-**	**	**/**	**	**	**	**-**-**	**/**	**/**	**/**	**/**
4.19	Mo	39-35	34	41/34	38	42	35	32- 0- 0	32/30	40/40	30/41	37/37
4.20	Tu	34-41	35	39/31	38	30	**	35-39- 0	32/30	40/40	30/41	37/37
4.21	We	31-32	39	34/39	34	32	35	40- 0- 0	30/32	40/ 0	41/30	37/37

Fig. 2 Duty Schedule is displayed in response to Selection "O". It lists, for the period selected (1 thru 275 days), the date, day of week, and 11 activity categories.

Where Fluo. represents Fluoroscopy

Alt5	Alternator #5 (General film reading)
am WR pm	Wet reading (a.m. and p.m.)
Conf	3:30 Film Conference
Lat	Late Stay
S.A	Sunny Acres (Outside hospital)
CME	Continuing Medical Education
US	Ultrasound
CT	Computed Tomography
Nm	Nuclear Medicine
Ang	Angiography

The numerical values correspond to I.D. numbers assigned to each participant.

1. DRS CODE NR : 41		NAME :			
2. FLUOROSCOPY/BRONCHOGRAMS :	1	10	20		
3. ALTERNATOR #5 :	1	3	10		
4. WET READINGS :	9	9	23		
5. 3:30 FILM REVIEW :	9	11	5		
6. LATE STAY :	9	19	5		
7. SUNNY ACRES :	0	0	0		
8. CME :	1	12	12		
9. ULTRASOUND :	0	0	0		
10. CT :	0	0	0		
11. NUCLEAR :	1	3	3		
12. ANGIO :	0	0	0		
13. SATURDAY MORNING :	1	1	0		
14. DO NOT SCHEDULE ON :	5	0	0	0	0
15. WILL BE ABSENT FROM,TO :	405	409	16.	:	0

Fig. 3 Individual Participant Listing. After entering the participant's I.D. number and name, the numerical rating assigned for frequency of participation in each of the activities #2 thru #13 is entered in the first column. (The second and third columns show ranking for future participation, and frequency of participation since January 1, respectively). Functions 14 and 15 permit entry of constraints such as unavailability due to meetings, vacations, teaching, research.

b) Participants. In response to selection "4" on the main menu, the corresponding function screen ("To CONSULT or MODIFY a Drs. availability") is displayed (Fig. 3). Each participating faculty member's name is inserted, and is also assigned an ID number.

c) Rating. Each participant is now assigned a numerical value (0-99) for each of the eleven activity categories (Fig. 3, #2 thru #13). Depending on the number selected, he will never be selected for the activity (0 selection), or will always be selected (99 selection). Intermediate numbers will result in an intermediate frequency of selection.

DATE (MO,DAY) :	4	5	Mo			
1. FLUOROSCOPY/BRONCH (all day) :	30					
2. FLUOROSCOPY/BRONCH.(am) :	32	ALT:	35			
3. ALTERNATOR #5 :	34	ALT:	35			
4. WET READINGS (MORNINGS) :	39	ALT:	35			
5. WET READINGS (AFTERNOONS) :	32					
6. 3:30 FILM REVIEW CONF. :	38					
7. LATE STAY :	30	ALT:	29	32	36	
8. SUNNY ACRES :	35					
9. CME :	34	39	0			
10. ULTRASOUND :	29	29				
11. CT :	40	40				
12. NUCLEAR :	36	36				
13. ANGIO :	37	37				

Fig. 4 Duty schedule for a single day. Gives a listing of all activity categories, the participant assigned, and a listing of alternates. Manual scheduling or rescheduling is interactive with the main schedule, and both are continuously updated.

d) Constraints. For each day of the week, prohibitions on scheduling are entered in morning, afternoon, and evening partitions. The code used is in the format:

20 = Tuesday afternoon

200 = Tuesday evening

341 = Wednesday evening, Thursday afternoon, Monday morning.

Absences due to meetings and vacations are entered under the "Will be absent from, to" category (Fig. 3, #14 and 15).

The schedule is created by selecting item "2" from the main menu, ("Schedule UPDATE"). The period to be covered by the schedule is selected (1-275 days), and displayed in response to selection "0" ("LIST schedule"). Where difficulties are encountered in achieving a solution for a particular day, the program will pause, and request a proceed command. Manual scheduling may be performed at this point, and is

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Nr	Name	Fluo	Alt5	W.R.	Conf	Late	S.A.	US	CT	Nm	An	SAlam	CME
28		0	0	0	0	0	0	0	0	0	0	0	0
29		0	0	0	0	9	0	99	0	0	9	1	1
30		1	1	9	9	9	0	30	20	1	0	1	1
31		1	1	9	9	9	0	0	0	0	0	1	1
32		1	1	9	9	9	0	10	0	0	1	1	1
34		1	1	9	9	9	0	0	0	0	0	1	1
35		1	1	9	9	9	99	0	0	0	0	1	1
36		0	0	1	0	9	0	0	0	99	0	1	1
42		0	0	0	0	9	0	0	0	0	0	0	0
37		0	0	0	0	0	0	0	0	0	99	0	0
38		0	0	0	9	9	0	0	0	0	0	1	0
39		1	1	9	9	9	0	0	0	0	0	1	1
40		1	0	1	0	9	0	0	99	0	0	1	1
41		1	1	9	9	9	0	0	0	1	0	1	1

Fig. 5 Summary table listing availability of all participants for each activity, showing the numerical value for the ranking assigned.

facilitated by selecting item "1" from the main menu, ("To CONSULT or MODIFY a day's schedule"). This presents for that day, a listing of all activity categories, participants selected for the activity, and a listing of alternatives (Fig. 4). If rescheduling is performed at this point, the selection is interactive with the main schedule, so that both it and the list of alternatives are continuously updated.

Once the system is primed as indicated above, the maintenance phase consists of confirming the data already entered, and then for each future schedule period (say the next month), entering vacation and meeting absences.

Other listings that are useful to schedule management are:

a) Listing of participants' availability, which is a summary showing the rating by activity for all participants (Fig. 5).

b) Listing of participants' unavailability, which summarizes "do not schedule on" and "will be absent from" constraints for all participants (Fig. 6).

c) Listing of participants' past involvement, which summarizes the

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Nr	Name	Do NOT schedule on					Absent from - to (MoDay)					
28		0	0	0	0	0	0 to 0	0 to 0		0 to 0		
29		0	0	0	0	0	412 to 416	419 to 427		0 to 0		
30		4	0	0	0	0	507 to 507	0 to 0		0 to 0		
31		11	2	0	0	0	415 to 416	0 to 0		0 to 0		
32		20	0	0	0	0	0 to 0	0 to 0		0 to 0		
34		0	0	0	0	0	426 to 426	0 to 0		0 to 0		
35		0	0	0	0	0	422 to 423	426 to 507		0 to 0		
36		200	0	0	0	0	419 to 423	0 to 0		0 to 0		
42		0	0	0	0	0	430 to 430	510 to 514		0 to 0		
37		0	0	0	0	0	322 to 402	0 to 0		0 to 0		
38		0	0	0	0	0	0 to 0	0 to 0		0 to 0		
39		50	0	0	0	0	0 to 0	0 to 0		0 to 0		
40		0	0	0	0	0	0 to 0	0 to 0		0 to 0		
41		5	0	0	0	0	405 to 409	0 to 0		0 to 0		

Fig. 6 Summary table listing unavailability of all participants, showing coded standing constraints ("Do not schedule on") and absences for meetings, vacations, etc.

number of schedulings by activity for all participants (Fig. 7). This represents a cumulative listing since January 1.

DISCUSSION

Although computer applications in information management and process control in radiology are fairly widespread, we believe the system described here represents the first practical application of a scheduling system to an academic department of radiology. The design is intentionally flexible to permit transfer to other sites of application. This system has been in operation for over eight months and demonstrates so far achievement of all goals as evaluated by staff. Of particular note is the ease of access in "lateral" mode within subsets of the main menu selections. Thus, the system design provides for easy movement from a given day's display under selection "1" ("To CONSULT or MODIFY a day's schedule," Fig. 4), to a given participant's display under selection "4" ("To CONSULT or MODIFY a Drs. availability," Fig. 3), without the necessity to first return to the main menu. This ability to move in lateral mode within the branching choices of the main menu results in

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Nr	Name	Fluo	Alt5	W.R.	Conf	Late	S.A.	US	CT	Nm	An	SATam	CME
28		0	0	0	0	0	0	0	0	0	0	0	0
29		1	0	0	0	5	0	86	0	0	18	0	12
30		16	9	13	3	5	0	19	10	9	0	0	12
31		21	7	14	8	5	0	0	0	0	0	0	13
32		19	8	15	4	5	0	9	0	0	6	0	10
34		17	6	20	11	3	0	0	0	0	0	0	10
35		16	9	16	5	4	21	0	0	0	0	0	10
36		2	0	0	0	5	0	0	0	104	0	0	12
42		0	0	0	0	5	0	0	0	0	0	0	0
37		0	0	0	0	0	0	0	0	0	92	0	0
38		1	0	0	16	6	0	0	0	0	0	0	0
39		15	9	15	6	4	0	0	0	0	0	0	8
40		1	0	0	0	6	0	0	104	0	0	0	12
41		20	10	23	5.	5	0	0	0	3	0	0	12

Fig. 7 Summary table listing past involvement for all participants. The listing is cumulative from January 1, and shows the number of occasions each participant has been assigned for each activity.

rapid operational adjustment between participants in different selection modes. Fine tuning to accommodate last-minute preferences, and unexpected absence due to illness, are also rapidly entered.

It should be noted that requests such as "I prefer to be assigned on ..." cannot be accommodated within the binary logic of the program, but can be accommodated through the manual scheduling provision.

Finally, once the basic constraints have been entered, maintenance consists principally of recording upcoming vacations and absences, and a full month's schedule is created in under ten seconds.

Besides the savings in man-hours spent on manual scheduling, and the improvement in morale due to elimination of frustration and conflict, an unintended benefit of a program is the acquisition of data that is useful in Departmental management applications. Thus, the initial assignment of numerical rankings according to activity category sharpens and clarifies the role definition of each participant. Secondly, the cumulative data

provide an insight to the distribution of effort by activity category that is extremely useful to decision-making in relation to recruiting and departmental planning.

FACTORS TO CONSIDER WHEN CHOOSING AN OUTSIDE BILLING AND PRACTICE MANAGEMENT SERVICE

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Not long ago, there was only a handful of companies offering data processing services or facilities management for Radiologists. Today that's no longer true. The competition for the Radiologist's business has increased dramatically over the past three to five years, and now he may choose from a wide range of outside billing systems and practice management services.

While this makes it tougher for vendors to make a living, the consumer benefits from reduced costs and improved service; and this is the way it should be in a free enterprise system. On the other hand, the proliferation of services makes it more difficult to sort out all the vendors and their products, and to decide which approach is best for the practice.

This paper attempts to describe those factors which should be considered when looking for a vendor. Offered is a discussion of selection criteria, and some guidelines to assist in making a decision.

Description Of Outside Services And Systems

What is meant by an outside service? Essentially, they are grouped into two categories: service bureaus and practice management companies.

Service bureaus range from someone with a computer who prints patient statements to companies which provide programming services, process data, produce output (bills, claims, reports), and contact patients for collection follow-up. In between, there are several variations, mostly having to do with the way data are input and the amount of information generated at the other end. "Buzzwords" used include batch-processing; off-line data entry; and on-line, interactive, real-time update.

Batch-processing means simply that the raw data is carried or mailed from the Radiologist's office to the service bureau for input and processing. Then the insurance claims, reports, and patient statements are returned for review, sorting, and mailing by office personnel. In some cases, the service center will mail the claim forms and statements directly to the patient, if the Radiologist chooses.

Off-line data entry describes the process whereby an input device is used by the physician's office personnel to enter data to a magnetic tape, disks, or diskettes (which are just varying forms of storage media). These are then sent to the service bureau for processing. The input device is not directly connected to the vendor's computer equipment, hence the name off-line. On-line, interactive, means the input device in the physician's office is linked to the host computer by way of a telecommunications network. The data entered goes directly into the computer's memory. If the host computer updates its files

with the information received immediately, instead of holding it for processing later, this on-line interaction is said to be real-time.

Facilities or practice management is a bit easier to define. Companies which contract this service handle the practice's accounts receivable, manage the business office, and in some cases, assist it in full practice management. This includes periodic reviews of fee schedules, practice profitability, third party payor relationships, pension and profit sharing programs, charge audits, and generally whatever it takes to achieve the maximum return on the Radiologist's charge dollar.

Now turning to those factors to be considered when evaluating vendors of outside systems and services, the first is Vendor Capability.

Vendor Capability

This one is listed first because the practice will sink or swim with the vendor chosen. Next to selecting a lifelong spouse, the choice of a vendor will have more to do with the Radiologist's personal happiness or misery than any other decision made. The time spent in searching for the right vendor will prevent many problems down the road. Obviously, anyone who uses the physician's practice to learn how to do medical billing should be avoided. Instead, choose someone who has extensive knowledge and experience in medical billing.

Deciding On A Service Bureau

These then are the factors to consider when evaluating prospective vendors. The decision to go with the service bureau approach depends on several variables. The size of the practice is one of the most obvious: the smaller the volumes, the more cost effective is a service bureau.

Also, a group's tolerance level for the hassles of running a business office play a large part in deciding how much it's willing to spend, while the capital available will dictate how much it's able to spend. The willingness to give up at least partial control of the group's accounts receivable and the practice's privacy will have to considered as well. It all comes down to a cost-benefit comparison and what it is worth to have a service bureau handle the practice's billing.

If a service bureau approach is decided upon, here's one way to proceed.

1. First, prepare a Request for Proposal or some other document to state the practice's expectations.

2. Then, locate vendor candidates. Every major city has one or more service centers and they can be found as simply as looking in the Yellow Pages under Data Processing Services. Also, check out the data processing services offered by nearby banks and CPA firms. But a word of caution is in order here: se-

lect only those banks or CPA firms which have experience in medical billing.

3. Send the Request for Proposal to selected candidates, and based on the responses, narrow the field of choices and ask for a sales presentation. Ask also for the names of current and past clients to call for references. Chances are slim the vendor will volunteer any "uglies", but present clients may be asked for any they know. Check also with the Better Business Bureau for any unresolved complaints.

4. Visit the facilities, if possible, and look for such things as written procedures and system security and back-up. Also, consider the center's overall appearance and organization; if possible, talk with some of the personnel. The purpose of the visit will be to let the vendor know the group's concern for professionalism.

5. Also while visiting the facility, note the names of the vendor's suppliers. Then contact them and ask about the vendor's financial stability and longevity. Don't be hesitant to ask the vendor's competitors about him either; the way they respond will tell something about them as well.

6. After all this, if there is more than one survivor, now is the time to go with emotions and pick the one the group is most comfortable with.

Deciding On A Facilities Manager

If the service bureau approach is not right for the group, then perhaps facilities management is. If so, prospective vendors can be identified through the American College of Radiology's Management Consulting Service. Also, talk with satisfied colleagues who are already using a company and refer to professional journals for leads as well. There are several small management companies springing up around the country, but the group would be better advised to consider a national company with a large base of satisfied clients.

Once a possible vendor has been located, a practice evaluation should be asked for. Almost all companies charge for this, but it may be possible to have the charge waived if the group contracts for practice management. At any rate, the evaluation will offer a chance to do business without committing long-term.

Where possible, visit clients or at least call for references. Do not be too polite to ask for both the good and bad news; remember, this is the individual or company who will make life either carefree or miserable. Finally, remember to select a vendor whose fees are tied to the group's net collections and whose profitability depends on how well he collects the physician's money.

Look too for a company with a large, satisfied client base and an established track record. These points may sound simple and axiomatic, but many practices are in trouble today because they did not spend the time to get to know their vendor, or delegated it to someone else.

Equipment Reliability and Back-Up

The next factor is Equipment Reliability and Back-Up. Even when contracting with an outside source, ask about the computer equipment used; after all, the vendor is only as good as his hardware. Find out the name of his equipment and call the local service office and ask about the frequency and nature of service calls. It is amazing how disarmingly honest computer repairmen can be at times.

Also, ask the vendor himself about back-up in case of extended down time. Does he have access to other computers? Is he dependent on one piece of equipment, or does he have others he can double up on?

Some practice management companies will sell a computer to the Radiology group and lease it back, but still assume responsibility for its maintenance and back-up. Other companies have set up management centers in major cities. These centers have computer equipment that is owned by the vendor and shared by several practices, just like a service bureau. The difference is these companies also provide the practice management services described

earlier. In any event, equipment reliability and back-up is something to be concerned with even when looking at outside services.

Programming And Technical Support

Another thing to look for is the vendor's programming capability and technical support. Today, there is really very little difference among vendors in terms of price and product; or at least there should be. The thing that sets them apart is the support after the sale has been made.

Since computers are used in the billing business, it stands to reason that the vendor with the largest and best qualified staff of programmers will do the best job supporting his products. But, there are other variables. What is the ratio of support personnel to clients? How long does it take to have a program change made? How well documented are the programs and office procedures? The list goes on, but the point is even with outside services, programming capability needs to be considered.

The same is also true with technical support, and this extends beyond just computer equipment or hardware. If the group contracts with an outside practice management company, what resources do they have to improve the profitability of your practice and increase your take-home dollar? What makes them the experts on third party reimbursement, fee schedules and pricing, investments and business office operations; also, personnel, purchasing, and practice accounting. Seek out their

support staff and examine its credentials. Practically anybody can promise you anything, it's the support after the sale that counts.

Ease Of Installation And Implementation

Support also includes how easily the system is installed and implemented. This is true regardless if you do business with a service bureau or a management company. Like most people, the Radiologist may wait until a problem has become a crisis before taking action. Then once a solution has been decided upon, it must be implemented yesterday, and that's when the trouble begins. The vendor is not about to walk away from the business, so he tells the Radiologist "no problem". But, any conversion is traumatic. The dangers can be minimized by not having unrealistic expectations regardless of what the vendor says.

The simplest conversion is from a small manual billing system to a batch processing service bureau operation. The practice's ledger cards will be entered to the computer prior to "going live" and the office personnel will be taught how to batch the work and prepare it for input. From there, moving up the scale of available services, the conversion gets more and more traumatic. The advice here is to allow enough time as the complexity increases. How much is enough? There is no way of telling without looking at each installation. But the vendor should be asked for his written plan to install and implement

the billing system or practice management service. Specifically, the Radiologist should ask for GANT or PERT charts, target dates, milestones, anything to prove the vendor has a formal project plan. Otherwise, he will be flying by the seat of his pants come installation day, and quite possibly take the practice along for the ride.

System Availability And Turnaround

Once ease of installation and implementation have been considered, the next factor is availability and turnaround. Will the system or service respond to the physician or will he have to respond to it? When dealing with a service bureau, get as much assurance as possible that it will regularly meet the practice's time requirements.

For most conventional service bureaus, turnaround time can be relatively long. Typically the company will pick up the data and deliver the output several days or even weeks later. One-day turnaround is possible in some cases if a premium is paid. Even faster results can be obtained by installing an input device in the physician's office and link it to the bureau's computer. In any event, the vendor should commit to delivery of service on a timely basis.

If the contract is with a practice management company, the account manager assigned to the group should visit the offices regularly, monthly at least, and review the practice's goals and objectives. After all, this is what the Radiologist is giving up some of

his hard-earned dollars for.

System Security And Confidentiality

One danger of contracting with someone else to do billing is the loss of control over accounts receivable and patient records. One way to reduce this danger is to insist that the vendor carry Errors and Omission Insurance or some sort of Business Interruption Insurance. Also, if his employees are handling the practice's cash, make sure they are bonded against theft or embezzlement. It is the employees everyone least expects who may be quietly helping themselves to the physician's money.

Patient confidentiality and the privacy of the practice's financial records are also exposed to risk. The vendor selected should have procedures to safeguard these files. Only those people authorized by the group should have access to the practice's financial information. With in-house systems, this is easier to control, but then the responsibility for system security rests with the physicians.

Another thing to look for is how the vendor protects the practice's records against destruction. If a fire or some other disaster were to strike the business office today, chances are that a copy of the records are not stored somewhere else. This is just not practical to do. But with a computer, it's fairly easy to copy patient records to a tape or disk and store it away from the office. Nearly every service bureau does this routinely, sometimes two or three times a day. But it cannot be

taken for granted, and the vendor should be asked for his written disaster plan and procedures to back-up the files. This way, the group is protected against an interruption in its billing.

Ease Of Operation And The Need For Specially Trained Personnel

A strong point of service centers is the relative ease of operation, and the need for specially trained personnel is shifted to the center as well. This takes the problems quite literally out of the physician's hands.

But there are several options to choose from when it comes to data entry: batched, off-line, or on-line, and the one chosen affects the degree to which the practice needs to worry about ease of operation and trained personnel. The vendor should be asked what exists in the way of training for the office staff and how easy is it to operate the equipment. His answer will affect the last factor, which is cost.

Cost

Fixed costs are usually very low in dealing with a service bureau. The practice will need to make little or no investment in data processing equipment of its own or the staff to operate it. Of course, if input devices are used in the physician office, the costs will be passed along in the form of equipment leases, cost of telephone lines, and employee salaries.

It is possible to share in certain economies of scale when a service bureau is used. For example, volume buying of forms and avoiding fixed costs when there is seasonal activity or when billing activity for the practice otherwise varies. Also, the physician avoids the equipment cost, hardware maintenance expense, and the threat of machine obsolescence.

On the other hand, the variable costs associated with service bureau processing may be quite high and should be carefully investigated and compared. Typically, bureaus charge a fixed fee for each transaction processed or record updated, and the amount of computer storage used. But there are variations. Some charge a percentage of billings or of collections, while others charge a flat fee and then some unit fee above that, for each record handled. These costs increase in a linear fashion as volumes grow, unless the bureau offers a quantity discount. Finally, there is a hidden cost to the practice in that collection rates may fall below the desired level. As for the cost of practice management, a vendor should be selected whose fees are tied to the practice's collections somehow. The vendor's profitability then depends on how well he collects and manages the accounts receivable. Some companies charge a flat fee to cover fixed and variable costs and then a small percentage (usually 1%) of gross receipts as collected. The advice here is to avoid flat-rate contracts with cost-of-living adjustments that give the vendor no incentive to collect the practice's money or control costs.

Contract Time

Once a vendor has been selected, remember to get all promises in writing. Verbal promises are worth exactly what they are printed on.

Typically, the written agreement should include (a) the fee, (b) the term of the contract (most are for one to three years with an automatic renewal or 90-day cancellation after the first year), (c) an escape clause in the event of vendor incompetency, (d) liability insurance and employee bonding, (e) the conversion of the group's existing accounts receivable and its return should the contract be cancelled, (f) the specific expenses assumed by the vendor, (g) a guaranteed collection percentage, and (h) a sliding scale fee discount.

Some vendors have form contracts which are very simple and straightforward. Nevertheless, the group will want to have its attorney look it over before signing.

The personal and financial rewards of independent practice are very satisfying. But with it come many headaches, including patient billing, business office expense, practice management problems, and meetings with lawyers, accountants, and bankers. In short, all the things that take time away from the physician and his practice. Outside service bureaus and management companies can relieve the group of these headaches. But in the final analysis, only the group can determine how much it's worth to be rid of them.

WHEN SHOULD A RADIOLOGY PRACTICE SELECT A COMPUTER BILLING SYSTEM?

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In the approximately seventeen years that radiologists have been converting from percentage contracts to independent practice there have been three basic systems of patient billing available for their use. These three techniques have been referred to as the manual system, the semi-automated system (posting machine), and the automated system (computer). One very important differentiating factor in these systems has been that the manual system and the semi-automated system have both been classified as labor intensive while the computer approach has been classified as equipment intensive. Over the years there have been numerous improvements in radiologists' billing brought about by experience, education, and the advent of smaller and less expensive computers. The semi-automated system has virtually disappeared from this market since the cost of the equipment approaches the cost of a small computer and the cost of operation in most cases significantly exceeds the cost of operation of the computer.

Historically the decision on when to computerize the business office has been based upon the number of statements mailed out each month. This can be fairly accurately estimated by multiplying the number of patients examined per month by 2.3, which is the average number of statements sent to each open account. Some years ago it was frequently stated that you should be sending out in excess of five thousand statements a month to justify a computer. As the cost of computer systems has come down and the cost of employees has gone up this number has been significantly reduced. It is not uncommon to now be able to justify a computerized system for those offices which are sending out between two thousand and two thousand five hundred statements per month.

I suggest to you that there are two factors which the radiologist should consider when making a selection between a proposed computer system or an existing or proposed manual system for radiology professional fee billing. The radiology group should select that billing system which will result in the maximum net income for the radiologists and the minimum of administrative hassle for the radiologists. Each of these factors will be discussed at some length.

There are essentially five ways that a radiology group can increase their income. These are an increase in fees, an increase in the number of examinations performed, a decrease in the number of radiologists who are sharing the income, a decrease in the cost of collecting the money, and an increase in the collection percentage. The criteria which are relevent to the selection of a billing system are the last two of these five options.

The selection of a billing system can have a significant impact on the income of the radiologists. If you take a medium sized group of radiologists who are collecting $ 1,000,000 per year, a one percent increase in the collection percentage will result in an increase in income of $ 10,000. Obviously, a ten percent increase in the collection percentage will result in an increased income of $ 100,000. The cost of operation of a billing office is usually expressed as a percentage of the collections. I have observed business offices with a collection cost as low as six percent and as high as thirty percent. Our example group of radiologists will be able to increase their income $ 10,000 for every one percent that they reduce the cost of doing their billing. These two factors are of equal importance and both must receive serious consideration when selecting a billing system.

A computerized billing system has commonly resulted in a decreased cost of operation of the billing office in several areas. The most significant of these is a

lower personnel cost. For a medium or large practice it traditionally takes fewer employees to operate a computer system than it does a manual system. This is compounded by the fact that as the practice grows you add additional employees to the billing office at a lower rate with a computer system then you do with a manual system. The costs of a computer system are essentially fixed with little if any inflationary growth. The computer requires no fringe benefits, no cost of living increases, no vacation, no sick leave, no time off to care for sick children, and it does not get pregnant. Postage costs can be reduced by fifteen percent under the present Postal Service regulations since the computer can sort the statements into Zip Code order which permits the radiologists to take advantage of the pre-sorted rates. With the use of computer printed mailers the office can eliminate the need for statement folding equipment, envelope stuffing equipment, and automatic postage meters. A computer system frequently results in a reduction in the volume of retained records and when this is considered along with a reduction in personnel it is frequently possible to reduce the amount of floor space required for the billing office. This can result in a significant saving in rent.

Introduction of a computerized billing system can also have a significant influence on the collection percentage of the billing office. The employees in the billing office tend to stay more current in their work when they are using a computer system instead of a manual system. This results in more timely statements being sent to the patients which influences the patient to pay more quickly. If the patient has been in the hospital and is submitting a series of bills to an insurance company it is much more convenient for the patient if all of the bills arrive quickly after his or her discharge. A late bill will not be included in the initial filing with the third party carrier and may be delayed for quite some time. Computer printed

bills are usually more professional in their appearance than bills generated by a manual system. The necessary codes for third party carriers are automatically included so that insurance filing is simplified for the patient. Followup on third party payers is automatic and does not tend to slip through a crack. When operating a manual system it is easy for this area to be slighted when the work load becomes excessive. When patients make telephone inquiries regarding their bills from the radiologist, the response to those inquiries when a computer system is in use is usually much more rapid and frequently more accurate. This improves the relationship between the patients and the radiologists which can result in a quicker payment of the accounts. Delinquent accounts are automatically identified with a printed list of these accounts along with their telephone numbers and financial history. This permits the office to have a more organized followup of delinquent accounts which results in a higher pay ratio and fewer accounts being turned over to the collection agency.

Minimization of the business office administrative headaches for the radiologists is also essential but difficult to quantify. The radiologists should be essentially free to practice medicine and not have to spend a great amount of time with corporate business problems. The choice of a billing system can have a significant influence on the amount of radiologist time required to operate the billing office.

The biggest cause of administrative problems in the billing office involves personnel. The potential always exists for such a problem at every interface between two individuals. If you have six employees in the business office you have fifteen employee interfaces and therefore fifteen potential problems. If you reduce the number of personnel to four you only have six employee interfaces. Since the introduction of a computer system will most frequently result in a reduction in the

number of personnel in the billing office, this can have a very significant influence on the numbers of personnel problems which can occur in the business office.

The introduction of a computer into a business office will not automatically organize a disorganized office. It will quite commonly cause the employees in a disorganized office to become organized so that they can meet the demands of the computer. A computer system should not be selected if the radiologist and/or the employees of the business office refuse to organize their operation.

If the operation of the office is organized and a computer system is introduced, several benefits can accrue automatically for the management. Claim forms for third party carriers are automatically printed by the computer with no additional activity required on the part of the employees. With minor cooperation from the hospital, these claim forms can be submitted directly to the third party carrier without a patient signature. This can result in a great reduction in confusion for both the employees and the patients.

Audit trails of all transactions are maintained by the computer system, which should result in reduced accounting costs and increased safety for the radiologists. It takes a much more sophisticated employee to steal through a computer system than through a manual system. A manual ledger card can be destroyed with virtually no historical track to identify this action. Any attempt to remove a record from the computer files will result in a printout of this action.

The availability of accurate and timely statistics on the business office operation can be of great assistance to the radiologists in making management decisions. Virtually all computer systems on the market for radiology billing have the capability to generate these statistical summaries at the end of each month and at

other intervals on demand. The availability of accurate descriptive statistics can eliminate much of the guess work from practice management and thereby reduce the amount of radiologist time required for supervision of the business office.

In summary, a radiology group should consider the introduction of computerized billing when it can be reasonably demonstrated that the introduction of a computer billing system will increase the net income of the radiologists and reduce the administrative headaches of the radiologists. Computerized billing is not a panacea and cannot be justified for all radiology practices. It should be obvious that a radiology practice with only one or two radiologists will find it quite difficult to justify the cost of a computer. A computer should not be installed to satisfy a desire for the most modern piece of equipment with the maximum number of blinking lights. Nor should a computer be installed because one of the radiologists has learned how to program and wants a piece of equipment to practice on. This is one of the quickest ways to turn your billing system into a disaster. You should remember that the computer is a dumb box which will do what it is told to do and only what it is told to do. It has the capability to very efficiently perform mundane and repetitive tasks very quickly, without tiring, and at a reasonable cost. If the transfer of these mundane and repetitive tasks to a machine will meet the criteria expressed above for a good system, then it is recommended that you seriously investigate the possibilities of introducing a computer into your practice.

FACTORS TO BE CONSIDERED IN SELECTION OF AN AUTOMATED IN-HOUSE RADIOLOGY BILLING SYSTEM

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INTRODUCTION

Ten years ago I was a practicing radiologist, who knew virtually nothing about computers. I had heard the term "software" many times, but had no idea that it referred to programs used to control and direct a computer. In my ignorance I had assumed that software was the papergoods used by the computer for printing bills and reports. Since then I have learned a little about computers and software and no longer practice radiology, having been modestly successful with a company I started to sell accounts receivable management and billing software to radiologists and other physicians.

While many of today's radiologists have been exposed to computers and data processing concepts during training and practice, most radiologists still acknowledge large areas of uncertainty regarding computers, especially when used for billing purposes. Lack of knowledge and/or misinformation about computers and software, compounded by lack of experience in radiology billing and business related matters, make many radiologists vulnerable to significant misunderstandings, dissapointments and frustrations when buying or leasing an in-house automated billing system.

SOFTWARE - GENERAL INFORMATION

Because no computer can do more than it is programmed to do, the most important consideration when selecting an automated in-house radiology billing system is the software.

A PROGRAM is a sequence of precise instructions to a computer, written in a special language or code the computer can interpret. A program tells the computer where to get input, how to process it and what to do with the results. Each job to be done by a computer requires a separate program, which specifies distinct operations to be performed on specific input to obtain certain unique output. SOFTWARE is the term applied to a set of programs which collectively are designed to accomplish a specific job. There are two basic types of software, operating software and application software.

OPERATING SOFTWARE is, as the name suggests, a set of programs which control and support the basic functions and operations of the computer, such as sorting data, doing mathematical calculations, determining job sequences and priorities, etc. The operating software, which is usually provided by the computer manufacturer, is the foundation upon which all other computer functions are based. If the operating software is less than excellent, no matter how good the application software, the performance of the computer will be suboptimal.

APPLICATION SOFTWARE is a set of programs designed for a specific

computer job or application - in this instance, radiology accounts receivable management and billing. To enter patient demographic information into a computer requires one program; to apply payments requires a second program; to produce bills or Medicare claim forms or an Accounts Receivable Status Report, etc., requires a separate special program for each job to be done. Each program may contain many thousands of characters of coded instructions to the computer. If any one of these characters in any one of the programs were miskeyed or if the logic (instructions) in one of the programs were not correct, the computer output would be incorrect. Software is an extremely complex and unforgiving modality which requires meticulous, painstaking attention to detail and considerable testing and "debugging" to insure that the system performs according to the specifications of the user. However, once written, tested and debugged a software system should perform flawlessly for as long as it is used. Software cannot break down.

Software is the key to the efficiency of collections and the cost of operation of any automated radiology billing system. The importance of software to a radiology billing system cannot be overstated. The better the software, the more comprehensive the software, the more fully customized the software, the better the system will operate and the fewer will be the number of people required to operate it. The purpose of an automated radiology billing system is to maximize collections and minimize cost of billing. Automation tends to increase control over receivables, which translates into higher collections and,

at the same time, to decrease need for personnel, which translates into a lower cost of billing.

While the initial cost of a comprehensive, automated in-house radiology billing system may be high, this cost is customarily spread out (amortized) over a number of years so that the monthly cost of the system is relatively low. The monthly cost to the group for personnel to operate any automated radiology billing system is invariably much greater than the monthly cost of the system itself, a consideration which makes it all the more important to select the radiology billing system which is most fully automated and most closely meets the needs and preferences of the group. Any initial or ongoing extra cost for the best software system should be more than offset by the increased collection efficiency and decreased personnel requirements of that software system. The radiology group concerned with efficiency of collections and economy of operation cannot afford anything less than the best software.

SOFTWARE - CUSTOMIZATION

Good software systems are evolutionary over time, resulting from good ideas enhanced with innovative programming and modified in accord with user feedback. It is such a software system, specifically designed for a particular use (radiology accounts receivable management and billing), that becomes an excellent departure point for further customization to meet the specific needs and preferences of the

prospective user.

Radiology billing requirements vary considerably from state to state and from practice to practice. Assuming a computer is capable of performing the job, it is the software that determines the suitability of any in-house billing system to the radiologist's billing needs and preferences. A generalized or standardized accounts receivable management and billing software system, even one written for radiology use, no matter how well designed, is usually not completely suitable to any one radiology group's needs and preferences, and will probably require some amount of customization. One of the reasons the radiologist should consider his own in-house computer system is to avoid the off-the-shelf standardization which characterizes the outside computer billing service. If the radiologist goes to the expense of having his own in-house computer system he should have a unique, custom software package which will express the accounts receivable management and billing needs and preferences of his group.

The software for in-house use by any radiology group should be customized from a basic radiology software package after an in depth, on site assessment by the software provider to insure proper handling of special accounts receivable and billing problems unique to that radiology group. For example, most radiology software billing systems are set up to require entry of patient demographic and insurance information from the hospital face sheet before charge data can be entered. While this method of data entry works well for most radiology

groups, there are those groups that receive face sheets on all hospital patients, even though only a small percentage of these patients may have been X-rayed. Because it would be very tedious and expensive to key all patient face sheets merely to apply charges to a small percentage of them, and almost as tedious to manually match face sheets and charge tickets so as to enter only those with charges, the group with such a data acquisition problem should be able to have its data entry method customized to accommodate entry of charges first. Then, when the hospital number on the face sheet is keyed, the operator will immediately know if that patient has had an X-ray, in which case the information on the face sheet can be entered, or if that patient did not have an X-ray, in which case the information on the face sheet need not be entered.

This example is presented as an illustration of how customization of the radiologist's software billing system can save time and money. Such a custom programmed method of entering charges before patient demographics saves the considerable personnel expense which would otherwise be required to (needlessly) enter all patient face sheets and eliminates the paper shuffling which would otherwise be required to hold and manually match charge tickets with patient face sheets prior to data entry.

Most hardware/software vendors, despite protestations or promises to the contrary, have little or no inclination to undertake the bother and expense of an in depth customization of their standard software package

to each user's needs and preferences. These vendors make the bulk of their profit from the sale of their hardware and are not eager to make costly and time consuming changes to their software. Most such vendors make only necessary changes required by third party payors, and possibly a few additional cosmetic changes to reports and refer to their software as customized. To be truly "customized", the user's software must be designed and programmed in accord with a user defined and a user approved system specification.

In contrast to the policy of most vendors of radiology billing systems to sell what they have in software, the true custom software vendor openly solicits from each new user group its informed input in the development of its radiology billing system. The custom software vendor should want to be certain that the group's new billing system meets all of the group's billing needs and preferences, not just the ones the group was aware of when they ordered the system. Most radiology groups are unaware of all the options open to them in automated in-house radiology billing. Many of these options when implemented result in significant savings in personnel and/or increases in collections, but also require significant additional custom programming and testing. It is extremely unlikely that any of the hardware/software vendors who are interested in selling their radiology billing system as is, with their standard software programs, would point out to any group the benefit(s) to be derived from optional program changes or additions. The custom software vendor, on the other hand, should be vitally interested in providing each radiology group

the best possible software system for its particular practice. Here is how it should be done.

The software vendor should spend two or three days on site with the radiology group collecting information on the group's billing needs and preferences and presenting various alternative data management and billing approaches for the group to consider. During the "pre-installation" visit the group's accounts receivable management and billing system should be carefully fashioned, one step at a time, with the members of the group and their billing office people making informed choices on each facet of how their billing system will operate and what it will do. All of the dozens of important choices regarding the design and implementation of the group's billing system should be made by the group - with guidance from the software provider, as needed. When the pre-installation visit is completed, a highly detailed system specification, covering every facet of the proposed software billing system (usually 75 to 80 pages) should be submitted to the group for its review and approval. When approved by the group, the system specification should become the blueprint for the group's custom programmed billing system and should be incorporated into a software agreement between the user group and the software provider as a guarantee to the group that its preferences and needs, as conveyed to the software provider, will be met.

The software agreement should further provide that if the group's custom programmed billing system does not meet the user defined

specifications, the user may return it to the vendor any time during the first year of use for a full and immediate refund in cash and that the vendor must, at the user's option, purchase from the user the computer upon which the billing system was used at the price paid by the user.

Since it is the software that determines the cost of operation and the collection efficiency of the billing system and since only a custom programmed software system will meet all of the group's needs and preferences, it stands to reason that a custom software system will cost less to operate and will collect more of the group's receivables than will any other billing system. In the final analysis, no group can afford to acquire less than the best custom software system available. Any mistake in software selection will constitute an ongoing expense to the group in lost receivables and unnecessary billing office salaries and benefits.

SOFTWARE - SUPPORT AND MAINTENANCE

Software, while highly detailed and complex, once written, tested and debugged, cannot breakdown in the sense that hardware can. Software is like the electrical wiring in a house; once it is installed and operating smoothly, there is nothing more to do to it, unless a change is required.

Mandatory third party payor changes and elective changes are needed by

every software user from time to time. The software vendor must be able to respond to the user's programming needs in a timely and cost effective manner. The software vendor should be able to support its software wherever it may be. Vendor support means keeping an up to date replica of each user's software system and being able to transmit program changes to the user on a timely basis.

Most software vendors have invested considerable time and money into their software systems. Since there is no way to effectively copyright or patent the trade secrets embodied in a software system, any software vendor with a system worth protecting does not release its source code. However, to protect the user of such a software system, there should be a provision in the vendor's software agreement for the free release to the user of all source code and documentation in the event that the vendor goes out of business or otherwise becomes unable to support its software system.

HARDWARE - GENERAL INFORMATION

HARDWARE is the general term applied to a computer and its peripheral equipment, if any. A computer is usually comprised of the following components: a central processing unit (CPU); a disk drive; an input-output (I/O) device; a printer. To ensure a working familiarity with basic computer terms and concepts, each of these four computer components is briefly described and discussed below.

The DISK DRIVE consists of a motor drive mechanism which spins a large disk in the computer at high speed and a read/write head which reads information from and writes information to the disk. The disk is a thin, circular platter coated with magnetic material on which software (programs) and data (processed information) are stored as tiny magnetic spot in a series of concentric circles called tracks. The data is stored on the computer disk in DATA FILES, some of which change from hour to hour as new billing information is added. The software is stored in a LIBRARY, which changes only infrequently.

The computer keeps its own record of where each program and each item of data is stored on the disk. A read/write head, which resembles a phonograph arm, is capable of moving rapidly from track to track as the disk spins beneath it at high speed. Programs and billing data stored on the disk can be read into the central processing unit (CPU - see definition below) for processing and data from the CPU copied back to the disk for storage via the read/write head with great rapidity. Information may also be copied in this manner from the computer disk to diskette or tape and vice versa. Copying of data and/or programs from the disk to the CPU for processing or to diskette or tape for backup leaves the original data and programs intact on the disk.

The storage capacity of the disk is expressed in megabytes (MB), with each megabyte representing one million characters of information. A computer with a 27.1 megabyte disk will store 27,100,000 characters of information (programs and data).

The CENTRAL PROCESSING UNIT or CPU is the data manipulating portion of the computer. The data manipulating capacity or "memory" of the CPU is sometimes referred to as "core" and is usually available in increments of 16K. 16K bytes of core or memory means that the CPU can manipulate (process) 16,ØØØ characters of information at one time. As the number of on-line terminals increases on any given computer, the amount of memory required to support those terminals increases proportionally, because the more terminals there are on the system, the more jobs the computer will be called upon to execute simultaneously. Insufficient core (memory) in a multiterminal computer results in prolonged terminal response time and degradation of printer speed if print spooling is not available. (A print spooler allows output processing to preceed independent of the printer by storing ready to print output on the computer disk until the printer is free.)

AN INPUT/OUTPUT (I/O) DEVICE is, as the name implies, a mechanism for putting information into the computer and for getting information out of the computer. In the context generally used, an I/O device is a keyboard for input and a video display screen for output. The printer is also an output device, but will be discussed separately.

Although not an I/O device in the generally accepted sense of the meaning the DISKETTE or FLOPPY DISK is, nevertheless, an extremely useful device for input and output of programs and data to and from a computer. The diskette is a small (8" in diameter), lightweight (one ounce), flexible magnetic disk permanently enclosed in a protective

plastic jacket for handling. By inserting a diskette into a special diskette drive mechanism on the computer, information can be copied from the computer disk to the diskette or vice versa.

A basic principle of data processing is to always have a backup copy of on-line data files as insurance against the loss of damage of those files. A backup copy of the user's accounts receivable data files should be made at least once each day as well as just prior to any significant change to the data, as would occur at the time of a cycle billing when all accounts in that cycle are aged. Diskette backup merely copies data from the computer disk, leaving the original data files intact on the computer disk. The backup is strictly for insurance and is actually used only if something happens to the data on the computer disk - a rare occurence, but an ever present possibility. If the data on the computer disk is damaged or lost, the data on the backup diskette(s) can be simply copied back to the computer disk to restore the data files as they were when the backup copy was made.

Diskettes, being lightweight, small, inexpensive and reusable are ideal for off-line (outside the computer) data storage and for sending programs and data through the mail. Diskettes are easier, more convenient and less expensive to use than a disk pack, the alternate conventional method of data backup used by some vendors. Eight diskettes, weighing all together about eight ounces and costing all together about $40, will hold the same amount of data as one ten megabyte disk pack, which is fifteen inches in diameter, weighs five to

ten pounds and costs about $150. Up to 20 diskettes at once (24 megabytes of data) can be accommodated by an automatic diskette changer.

A diskette is quite durable and flexible, as its alternate name, floppy disk, implies. It is highly unlikely that a diskette would be damaged if dropped. A disk pack, on the other hand, is quite fragile and if dropped, there is a high probability it would be sufficiently damaged to prevent retrieval of any data on it.

A PRINTER is an output device which produces a permanent printed record (hard copy) of a computer's output. There are character printers, which print one character at a time, and there are line printers, which print all characters in one print line simultaneously. Character printers are generally designed for low volume printing and do not hold up as well as line printers. A character printer is usually unacceptable for use in a radiology billing environment unless the output volume is very low. A line printer which prints 150 lines per minute (lpm) is usually adequate for most radiology groups with no more than 6,000 open accounts. For larger groups a 300 or 600 lpm printer would be more appropriate.

A matrix printer prints each character separately by arranging dots in the configuration of the desired character. The resulting character appears to the eye to be solid. A major drawback to matrix printers is that optical character readers (OCR) used by some third party payors to

speed processing of claim forms cannot read matrix print; this means all insurance claim forms with matrix print must be hand processed by the insurance carrier, delaying payment and introducing the possibility of a keying error by the payor.

HARDWARE - SUPPORT AND SERVICE

In the event of computer breakdown, local availability of the hardware vendor's service personnel is a matter of primary importance to any computer user. The radiologists, being dependent on sophisticated X-ray equipment, should be well aware of the importance of prompt, competent, local service to the smooth and efficient operation of an in-house computer. A well trained service representative should be on the job with whatever is needed to resolve the problem within an hour or two of being called. A computer is an electro-mechanical device and is subject to recurring breakdowns - some minor and some major - but all work stopping. Out-of-town or long distance hardware support, no matter how well intentioned, is often unsatisfactory, especially in the face of an airline strike or inclement weather or around holidays when airline seats are unavailable on short notice.

The availability (or lack) of local service is determined primarily by the type of computer vendor from whom the computer is acquired. For the purposes of this discusson, there are two basic types of computer vendors: the original equipment manufacturer (frequently referred to as "OEM") and the conglomerate computer vendor. The original equipment

manufacturer conceives, designs, manufacturers, markets, installs and services its own computers. By virtue of the large number of computers it sells nationally, the OEM is able to maintain a national network of service centers and service representatives in hundreds of locations throughout the country to support its installed systems. In contrast to the OEM, the conglomerate computer vendor (sometimes called Systems Integrator) purchases major computer components (central processing units, disk drives, printers and terminals) from various original equipment manufacturers, assembles these components into a conglomerate computer and sells that conglomerate computer, usually under its own name, to the end user, almost invariably with an application software package.

It is most desirable to have computer maintenance and service directly from the original equipment manufacturer, whose service representatives are well trained and experienced with the manufacturer's equipment. However, this nicety is precluded when dealing with a conglomerate computer system. While all computer manufacturers will service their own equipment, none will service equipment produced by other manufacturers. While the conglomerate computer vendor stresses the advantage of having hardware and software service from the same source, it is the exclusivity of service by the various computer (component) manufacturers that forces the conglomerate computer vendor, which mixes major computer components from different manufacturers, to provide its own service and support for the entire conglomerate computer system.

While most original equipment manufacturers offer medical billing software to encourage medical groups to buy or lease their hardware, these medical billing packages are designed for use by general medical groups (family practitioners, internists, gynecologists, etc.) and are not suitable for the billing needs of radiologists with their high-volume, non-recurrent, referral type practices with reduced direct patient contact. The conglomerate computer vendor has been able to develop a place in the medical computer market primarily by exploiting this software gap left by the original equipment manufacturers. By providing software for the relatively limited market of radiology (and pathology) billing, the conglomerate computer vendor has been able to sell its conglomerate computers to these specialty groups and to the occasional general medical user, who might not be aware of the disadvantages of owning a conglomerate computer system. However, because of the rather limited market for radiology and pathology automated billing systems, because of a lack of local service and because of a reluctance by most prospective users to pay a large amount of money for a conglomerate computer to a company that may not be around to service it in a few years, sales of conglomerate computers have been relatively few and sparcely distributed geographically.

Due to the sparce distribution of its users, the conglomerate computer vendor with national marketing aspirations cannot cost justify local service for most users, but must rely on a few regional service centers to support its users. Reliance on regional service centers means no local hardware support, prolonged service response time (often more

than a day and sometimes a week or more) and increased cost of service due to travel time and transportation expenses, which cost is ultimately borne by the user. Sparce distribution of conglomerate computers also means it is unlikely that a backup computer will be available should the user's computer go down for an extended period of time.

If the regional service center of the conglomerate computer vendor is geographically close to the user, direct support of the user by the vendor is usually no problem. However, as geographic distance between the two increases, the quality of service decreases. Computers, being electromechanical, are not infrequently plagued with intermittant or obscure problems, which require multiple service calls to find and correct. Such an intermittant computer problem could be very frustrating and costly in terms of down time and billing losses to the radiology group forced to rely on out of town service.

As previously stated, inclement weather or crowded holiday air schedules can significantly delay service response from a distance. With computers, as with X-ray epuipment, there is no substitute for fast, competent, reasonably priced, local service from the original manufacturer of the equipment.

The old market dictum, caveat emptor (let the buyer beware), applies nowhere as well as in the automated medical billing field. I have seen numerous instances in which a group paid $80,000 to $100,000 for a

hardware/software system consisting of a standard billing software package together with $25,000 or $30,000 worth of assembled conglomerate computer components, which on resale one month after purchase would not yield $10,000. I know of numerous radiology groups around the country who bought medical billing systems from various conglomerate computer vendors, which groups are now financially strangling on these systems, unable to do their billing without the expense of a large billing office staff and unwilling to get rid of the system because of the large investment it represents. A ten member radiology group in Kansas City, Missouri, after two years of overall poor performance, recurrent computer breakdowns of up to two weeks at a time with unsatisfactory long distance service from the conglomerate computer vendor in another state, finally bit the bullet, scrapped its conglomerate computer system and bought a new computer from an OEM together with a custom programmed radiology billing system. In the last year or so, other radiology groups in Columbus, MS, Pensacola, FL, Baltimore, MD, Knoxville, TN, San Diego, CA, and San Antonio, TX have done the same. I have talked with dozens of other users of conglomerate systems in the last few years who regret ever having bought their conglomerate computers, which they would be happy to be rid of, if only they could recover some of their investment.

A perfect example of the inherent deficiencies associated with the conglomerate computer is found in Northrop Data Systems, a now defunct conglomerate computer vendor that marketed its medical (primarily radiology) billing systems nationally. By offering a specialty medical

billing (radiology) package, by aggressive marketing and by exploiting the lack of sophistication of the prospective medical user regarding computers, Northrop Data Systems was able to effect a substantial early market penetration. When National Medical began operation in 1975, Northrop Data Systems was "the" competition. However, because of logistical problems associated with having to service its sparcely distributed users throughout the United States from only four or five regional service centers and because of the inherent deficiencies associated with the conglomeration of basic computer components which were not designed to be used together, and because of limitations and lack of flexibility in its software, Northrop Data Systems in May, 1980 ceased marketing its medical billing systems. The result of the precipitous withdrawal of Northrop Data Systems from the in-house automated medical billing market was that scores of medical groups throughout the United States that purchased a conglomerate computer from Northrop Data Systems were left with a very expensive "orphan". Although Northrop Data Systems is alleged to have originally promised its users that it would continue to service their systems, the company within six months of its cessation of marketing turned over its service responsibility to an outside computer service company with regional service centers in many, but not all, areas of the United States. Northrop users are now at the mercy of their service organization, as is evidenced by a substantial increase in cost of service since Northrop's withdrawal from the automated medical billing market.

The nature of the user's hardware service arrangement with a

conglomerate computer vendor sooner or later spells trouble for the user. Because the conglomerate computer vendor must provide its own computer maintenance and service to its sparcely distributed users, the more users the conglomerate computer vendor garners, the more difficult is the task of providing effective service at a reasonable price. When the number of users requiring service is relatively small, the conglomerate vendor can meet the demand. However, as the number of users increases, the ability to service all of them nationally from four or five regional service centers on a timely basis beqins to deteriorate. Eventually the point is reached, as with Northrop Data Systems, at which the deterioration in service and support begins to affect the reputation of the vendor and, thus, to affect the sales of new systems. As sales deminish, the incentive and the ability of the conglomerate vendor to render service deteriorates further until the point is reached where it is no longer economically feasible to continue operations, as happened with Northrop Data Systems.

Whether or not individual conglomerate computer vendors acknowledge or even perceive the logical and inevitable outcome of their being forced to provide their own hardware service on a national scale, the end result will be the same. The conglomerate vendor will sell its conglomerate systems while it can profitably do so and when it can no longer sell its systems, will bail out, as Northrop Data Systems did, leaving its users to more or less fend for themselves. Northrop Data Systems, as a subsidiary of Northrop Corporation, a Fortune 500 company, and as one of the first conglomerate computer vendors in the

medical billing field and (initially) the most successful, was the first conglomerate computer vendor to reach the service saturation point, where, despite the vast resources of the parent company, the inability to render effective service and user support adversely affected the vendor's reputation, which caused lost sales and soon thereafter a total shutdown.

In summary, the injudicious selection of an in-house automated billing system can be financially disasterous for a radiology group. If the group selects a conglomerate computer vendor as the provider of an in-house billing system and that vendor for whatever reason cannot adequately support and service the group or if that vendor ceases operations, the user is left with an orphan computer. This orphan is not only worthless for resale, but alternate service, if available at all in the user's area, is likely to be quite expensive. The risk of loss to the group using any in-house automated billing system is not limited to the amount spent on the system, but extends to the accounts receivable. Any significant interuption in the group's ability to get out its bills and insurance claim forms can have disasterous financial consequences. No medical group can afford to jeopardize its financial integrity by selecting a potentially inadequate computer vendor. Rather than take this needless risk, the prospective user of an in-house computer would be wise to select a computer that is manufacturered, marketed and serviced by an original equipment manufacturer with a well established national network of local service representatives. To do so is to be assured of the ongoing availability

of prompt, competent service at reasonable cost and to have the added assurance that the substantial amount of money invested in the computer is protected and can be largely retrieved at any time.

HARDWARE - BACKUP

The availability of a nearby backup computer, which can be used on short notice to enter data and run bills, is a matter of considerable importance in the event of a long term incapacity of the radiologist's system, as would occur following a flood or fire. The greater the number of backup computers available, the better the backup, since no one computer can be relied upon to be free for use when needed. Use of the same type and model of computer by general (non-medical) users is particularly advantageous, not only because of a larger number of potentially available backup units, but also because most of them, being used for non-medical purposes, would be available on short notice since their load periods would most likely differ from those of the radiologist.

For adequate backup, the radiologist's software programs and billing data must be transferrable from his computer to the backup computer without any need for reprogramming or reconfiguration. This means the backup computer must be virtually the same brand and model as the radiologist's computer.

HARDWARE - RESALE VALUE

Most prospective users of an in-house computer are not concerned with or even aware of the resale value of their soon-to-be-acquired computer. If the in-house computer is never sold or traded, its resale value is of little cosequence to the user. However, if the computer becomes inadequate for the needs of the radiologist because of practice growth or because of a desire to share the system with other users, or for any other reason, and the radiologist wishes to sell or trade the computer for a newer or larger model or for a different brand, the resale value of the computer is of considerable importance. Also, the actual (resale) value of the computer may figure prominently in any financial considerations associated with the buying in of a new partner or the cashing out of an old partner. The resale value of the computer may also figure significantly in the event of a casualty insurance claim.

Because of pending federal legislation affecting private medical practice in general, and radiology specifically, and because of the current medical malpractice situation, very few of us can say with any certainty how we will be practicing radiology or what our financial status will be in three or five years. Despite the political and economic uncertainties of independent radiology practice, a steadily increasing burden of billing paper work is coercing the radiologist in independent practice to acquire his own in-house computer system as an economy measure to protect against steadily rising personnel and/or

outside computer costs. All other considerations being equal, most radilogists would prefer to acquire an in-house computer system which would depreciate as slowly as possible in real value, since resale or exchange of the computer might be required in the future.

The factors which ensure a well sustained resale value of a computer are:

1. manufacture and nationwide distribution by a well-established computer manufacturer whose name is identified in the public mind with computers;

2. local service available nationwide from the original manufacturer;

3. widespread use of the computer by non-medical users

4. thousands of identical units already sold or about to be sold nationwide to assure adequate backup, everywhere;

5. state of the art technology and design;

6. ability to support various programming languages.

With the above factors affecting resale value, it is easy to see why certain brands of computers hold their value well, losing only 10% to 30% of their initial cost per year: IBM, DEC and Data General are all

original equipment manufacturers with national distribution and service, whose computers hold their value very well to fairly well in respective order. At the bottom of the list for resale value is the conglomerate computer, which meets few, if any, of the criteria for good resale value mentioned above. A conglomerate computer usually has little or no resale value, regardless of how well it runs, how long it has been installed or what its original cost.

The best way to protect the substantial investment required for an in-house computer is to buy a computer which will return a decent percentage of its original cost at resale - no matter how unlikely resale may seem at the time of purchase. A simple way to assess the market demand for, and, thus, the desirability of, any about-to-be-purchased computer is to determine its resale value before buying it. The resale value of any used computer can be determined by contacting a used computer broker. If a particular brand or model of computer has poor or no resale value or is not listed with a used computer broker, it is probably an off-brand or conglomerate computer and/or an obsolete model and should be considered carefully before being purchased.

An economical alternative to buying an expensive new computer from any hardware-software vendor is to buy the same computer from a used computer broker at a price well below new cost and buy only the software from the hardware-software vendor, if the vendor will cooperate. Such an arrangement could save the radiologist $15,000 to

$50,000, depending on the computer brand and size of the system. One very important warning, however, when buying used equipment, is to be certain that the particular computer being acquired is eligible for an ongoing maintenance agreement from the original vendor covering all parts and labor. The cost of such a maintenance agreement should be the same as it would be if the computer were purchased new from the original vendor.

SYSTEM GUARANTEE

The confidence of the vendor of an automated radiology billing system to meet the needs and preferences of the prospective user is reflected in the guarantee offered by the vendor. Some vendors offer no guarantee at all. Most vendors offer a thirty to ninety day guarantee covering only the computer, which is, in effect, merely a pass through of the computer manufacturer's guarantee. The software is usually provided as is - possibly with some changes requested by the user, but with no guarantee to meet user defined specifications. Many vendors have a clause in their contracts specifically disclaiming any responsibility for "fitness for intended use or marketability" of their systems. It behooves the prospective user of an automated radiology billing system to carefully read any contract to be signed with the vendor. The contract will tell volumes about what the vendor thinks of its own radiology billing system. The more restrictive and unilateral the vendor's agreement with the radiologist, the less secure is the vendor about the acceptance of its billing system by the radiologist.

The vendor of a custom radiology billing system should be sufficiently confident that each radiology group will be completely satisfied with its billing system to offer a one year 100% money back guarantee. The guarantee should state clearly and unequivocally that the software and the hardware must perform to the user's specifications for the first year of use or the user may return both the software and the hardware to the vendor for a full and immediate cash refund.

UNIQUE FEATURES OF THE PAR (PHYSICIANS' ACCOUNTS RECEIVABLE) AUTOMATED IN-HOUSE BILLING SYSTEM FOR RADIOLOGY

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The purpose of an automated billing system in a radiology billing office is to increase collections and decrease cost of billing. Increased collections are accomplished through better control over and better followup on receivables. Decreased cost of billing is accomplished primarily through decreased dependence upon personnel, although minor savings are also realized in postage, telephone and office rent. It has been National Medical's experience that when a PAR radiology billing system is used to replace a manual or outside computer billing system, the combined financial advantages of decreased cost of billing and increased collections achieved by the PAR system usually pay for the system (hardware and software) in six to eighteen months.

The PAR system has evolved steadily over the years to its present level of sophistication as a result of constant flow of new ideas and improvements modified by feedback from the more than 250 users of the system throughout the United States. Three of the special PAR features, which allow the system to function with optimal collection efficiency at minimal personnel cost are discussed below.

ON LINE VS BATCH PROCESSING

A significant advantage offered by the PAR system is the method used to enter new patients and transactions (charges, adjustments,

payments and comments) into the data base. Most accounts receivable systems use either a batch method of data entry or an on-line method. The batch method involves entry of a number of patients and/or transactions at the same time and is generally thought of as being off line and "blind", in that data entry is performed without feedback or visual verification of the accuracy of the data being keyed. This method of data entry (keying to punch cards or tape) was the norm before on-line video terminals were widely available. Because the entered information could not be verified until listed out, it was kept in a temporary "work" file until the keyed data could be printed, edited and corrected. When all the information in the work file was determined to be "clean", the records in the work file were merged into the data base.

On-line data entry (as its name implies) inserts newly keyed data directly into the data base without it going through a work file. This method of data entry became prevalent when on-line video display terminals replaced off-line key punch devices. On-line data entry, which permits immediate visual verification of the data being entered, is ideally suited for small amounts of simple data when minutes or seconds count, as in reserving the last available seat on a particular airline flight. However, such a method of data entry is not required, nor is it even appropriate, for large batches of complex data as are customarily keyed into a radiology accounts receivable system. Also, on-line data entry, unless backed up by on-line interactive edit checks and audit controls, has the potential

to insert significant amounts of inaccurate and/or invalid data into the data base.

To avoid the problem of corruption of the data base through entry of unedited data and yet be able to efficiently handle the large amount of billing data generated in a radiology practice, National Medical has elected to use a combination of on-line and batch data entry, which it calls, appropriately enough, "on-line batch entry". "On line", because there is interactive on-line editing of all data entered with immediate visual verification; and "batch", because all newly entered patient and transaction information is kept in a work file until it is determined to be absolutely "clean" and in balance with the source documents from which it was generated.

Thus, the PAR system enters data (patient demographic and/or transaction information) with interactive on-line editing of the information as it is being keyed. Information entered is kept temporarily in a work file, which can be printed on demand and balanced to the source documents used to generate it. Each data entry terminal generates its own work file(s). When data entry is completed at any terminal, the work file for that terminal is printed out for further review and/or editing. If no errors are found, the printout of the work file is kept as a permanent record of that batch of data. If errors are found on the printout, for example, patient name misspelled or batch does not balance to source documents, the necessary correction(s) can be made and a final proof copy (printout)

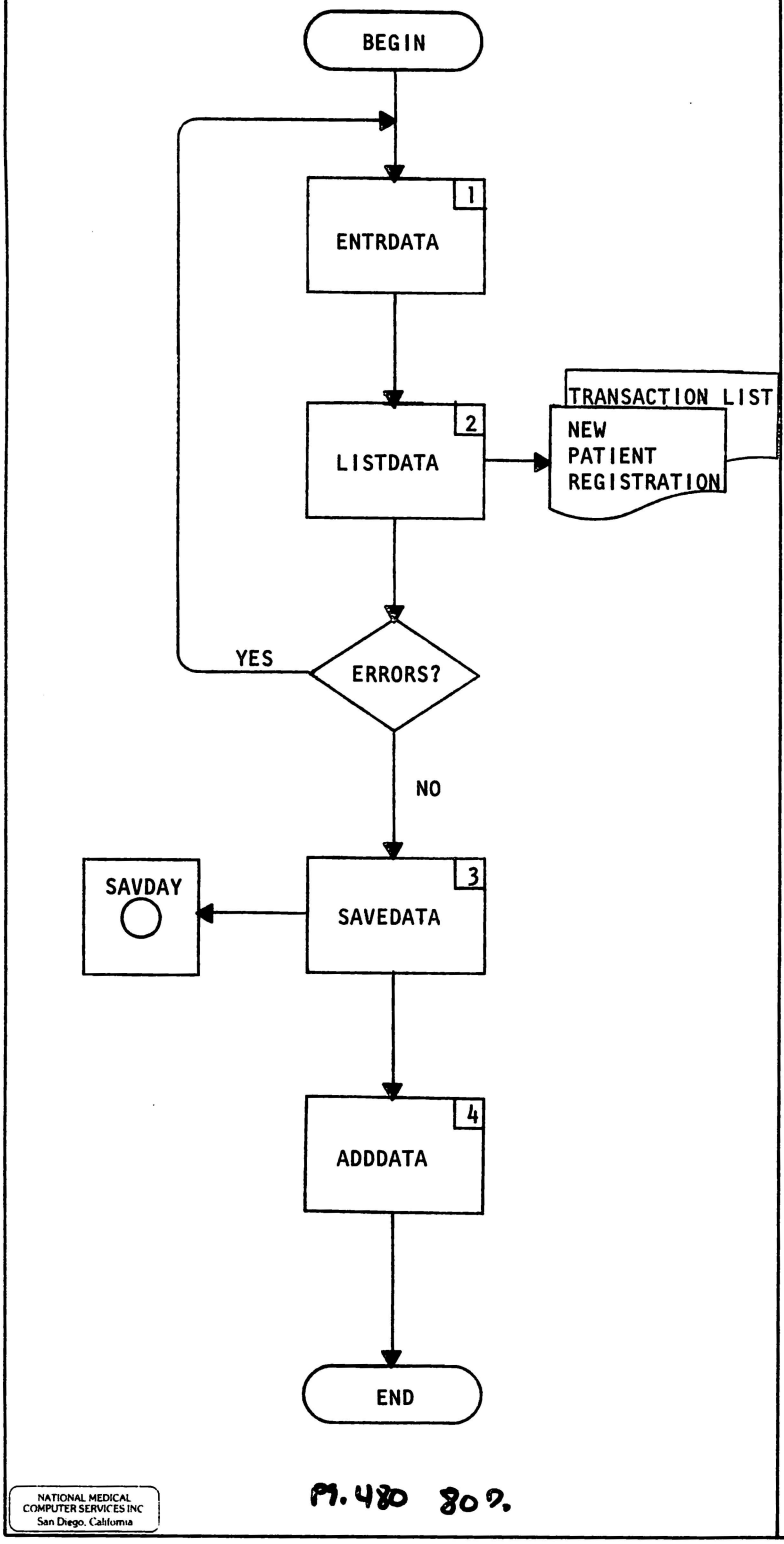
of that work file made as a permanent record of that data batch. A copy of the clean data in the work file on the large fixed disk of the computer is then saved on a floppy diskette to be held for a several days until determined that it is no longer needed. After a diskette copy of the work file has been made, the records in the work file are merged into the data base and the work file is deleted.

A schematic outline of the PAR data entry process taken from the PAR operators manual is presented on the next page.

The only inconvenience of National Medical's on-line batch method of data entry is that newly keyed patient and transaction information is available for inquiry only from the terminal of entry until merged into the data base (usually some 30 to 120 minutes after the start of data entry, depending on the size of the batch). With the PAR system, merging of new data into the data base may be done whenever desired (except during cycle billing and monthend) and does not interfere in any way with any other function of the PAR system. Because newly keyed patient and transaction records go into a temporary work file and not directly into the data base, the PAR system may be used to enter patient and transaction data during times when on-line systems are normally locked out, such as cycle billing and monthend.

The advantages of the PAR on-line batch method of data entry are:

TITLE	DATE	PAGE
ENTERING DATA	04/22/80	1 of 1



STEP	STEP DESCRIPTION
	See also - "HOW TO ENTER DATA"
1.	ENTER: 1 (from NWDATA menu) or ENTER: ENTRDATA
2.	ENTER: 2 (from NWDATA menu) or ENTER: LISTDATA
	DECISION Were errors detected during the -LISTDATA- procedure? If YES, continue with step 1, -ENTRDATA-, and make the necessary corrections. If NO, continue with step 3, -SAVEDATA-.
3.	ENTER: 3 (from NWDATA menu) or ENTER: SAVEDATA (Use *SAVDAY* diskette.)
4.	ENTER: 4 (from NWDATA menu) or ENTER: ADDDATA

Figure 1

1. Only clean patient and transaction records are entered into the data base;

2. New data may be keyed into the computer, edited and listed during times when the data base is in use, such as during billing and month-end processing, when users of on-line systems are normally locked out.

3. Each batch of newly keyed data is balanced to the source documents used to generate it. Therefore, the system is always in balance.

4. No data can ever be lost or need ever be rekeyed, no matter what happens to the computer or the data base, since each batch of new data is saved on floppy diskette and can be restored if and as needed.

5. As opposed to some on line systems, which must shut down at some time during each day or work through the night to process newly entered data, there is no restriction or limitation of use of the PAR system at any time due to data entry.

6. The productivity and quality of work of each data entry operator can be easily determined since the edit listing for each batch of data has a work station identity and date on it.

EDIT CHECKS & OPERATOR ASSISTANCE

By now, everyone has heard of "GIGO", for "garbage in, garbage out". Despite the widespread awareness of "GIGO", many automated radiology billing systems still offer inadequate automatic edit checks to verify what is entered into the data base. Many systems accept whatever is keyed or not keyed by the operator in each patient record. I have personally observed a radiology billing system on which the operator could key alphabetic characters into a numeric field and leave fields like billing (guarantor) name or billing address blank causing the patient's statement to be printed and mailed with no name or address. On this same system, the operator may even enter a non-existent billing class code, thus, "losing" the account into the system where it would never get billed or followed up.

As a result of National Medical's extensive experience with medical billing in general and with radiology billing in particular (over 80% of PAR users are radiologists) we have developed what we consider to be a simple to use, foolproof method of ensuring only clean data are entered into each user's data base. National Medical has made the PAR software programs highly sophisticated to allow the operation of the PAR system to be very simple. The PAR system evaluates each field of data entered and interacts with the operator in such a way that predictable errors cannot be made. For example, PAR can be programmed not to allow a Medicare patient to be registered into the

system as a Medicare account if the primary insurance (Medicare) number for a patient is not entered in the appropriate field. The operator must either enter a Medicare number or change the billing class from Medicare to private pay (or some other class). There is no point in opening a Medicare account for the patient if the claim will only be rejected for lack of a Medicare number.

On the PAR system there are 52 edit checks automatically performed by the computer as each new patient's billing information is entered. All 52 of these edit checks are performed in a fraction of a second after all information on the screen has been keyed and the "ENTER" key is struck. If no error was made during entry of the new record, PAR accepts the information and prompts the operator for the next patient's information. However, if an error was made during data entry, a message explaining the error is displayed at the bottom of the screen and an buzzer advises the operator of the error. When an error message is displayed, the cursor is automatically positioned at the beginning of the field containing the missing or erroneous data to facilitate correction. Listed below are examples of messages the operator would receive on the PAR system for certain keying errors or omissions. The error or omission generating each message should be obvious from the message text.

Patient last name cannot be blank

Patient first name cannot be blank

Zip code not on file

City cannot be blank unless valid zip code entered

State cannot be blank unless valid zip code entered

Birthdate is invalid

Address line one cannot be blank

Patient sex must be M or F.

Inout code must be blank for office visit - otherwise I, O, E or N

Inout code must be blank for this location

Inout code must be I, O, E or N for this location

Invalid billing class

Insurance key required for this class

Insurance key not on file

Referring doctor not on file

Dun code is invalid

Dun control must be P, H, S or blank

Invalid value for dun control counter

Admit date is invalid

Injury date is invalid

Discharge date is invalid

Message number must be zero or 1 through 99

Message number is valid but is not in message file

Rebill code must be I, S, B or blank

Discount amount must be positive for this billing class

A discount is not allowed for this billing class

Code to show insurance claim was denied must be "D"

The referring doctor number cannot be zero or blank

The discount amount cannot be greater than 100%

A primary insurance number is required with this class

A secondary insurance number is required for this class

ICDA code is not on file

Must have either an ICDA code or a free form diagnosis

An employer name is required for this billing class

A group number is required for this billing class

Date of birth is required for this billing class

Injury date is required for this billing class

As might be deduced from reading this list of messages, many of them are specific for certain billing classes and apply only under certain circumstances. There are similar error messages on the PAR system for transaction (charge, adjustment, payment and comment) entry, all designed to eliminate preventable errors and omissions by the operator and ensure that only the cleanest possible data reaches the radiologist's data base. Data entry on the PAR system is designed to compensate for operator inexperience and/or error.

TAILOR MADE REPORTS - ON DEMAND

To enhance the management of accounts receivable and improve cash flow and collection rate PAR offers the Class Report. The Class Report, which can be run on demand, is a user defined report listing all available information for each account meeting the specified profile. For example, the radiologist may wish to see a list of all private pay patients with Prudential insurance from billing locations 3, 4 and 5 (private offices) who have a balance due of $50.00 or more

and are 90 days or more delinquent. Or, all Blue Shield patients who are between 90 and 120 days delinquent (but not more than 120 days), with a balance due of $100.00 from location 1 (hospital), outpatient and E.R. only. Virtually any desired patient account profile can be run for general information or for patient followup. Such a powerful receivables management tool as the Class Report is highly valuable in optimizing cash flow and maximizing collections.

Because of time constraints, only three of many user oriented PAR features have been covered. Additional information on PAR is available from National Medical on request.

COMPUTERS IN INDEPENDENT RADIOLOGY PRACTICE

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INTRODUCTION

Since the early 1970's, radiologists in independent practice have been using automation in their billing and accounts receivable operations in ever increasing numbers. Today, this can be cost effective for hospital-based radiology practices of five physicians, and for practices of four to six physicians and above, automation is almost mandatory in order to achieve a cost effective operation. One form of automation which has proven to be successful is the in-house computer system, which operates in an on-line, real-time manner. Major factors in this success are ease and speed in both entering data and accessing information.

The purpose of this paper is to consider those concepts and philosophies of present, state-of-the-art computer technology which can have a direct practical impact on the effectiveness of radiology billing. We intend for this material to be useful in studying radiology billing systems and as such have endeavored to use straightforward terminology, to emphasize valid system capabilities as opposed to considering a specific system, and to be objective in considering various alternatives.

BILLING AND ACCOUNTS RECEIVABLE GOALS

In order to logically address those functions which a computer system should perform, we first consider the goals and subgoals of a typical radiology billing office. First, within the constraints of accurately billing for procedures performed and maintaining a good professional relationship with patients, the major goals are to maximize receipts and

minimize the number of days in accounts receivable. Here, the number of days in accounts receivable is defined as follows:

$$\text{Days In Accounts Receivable} = \frac{\text{Dollar Amount In Accounts Receivable}}{\text{Dollar Amount of First Billings During "N" Day Period}} \times N$$

(Where "N" is typically a 60 to 90 day period, e.g. N=60)

Keeping in mind, the constraints of achieving the above objectives and maintaining a well motivated and reliable billing office staff with low turnover, the second major goal is to minimize operating costs of the billing office. The third goal is to provide security for the assets of the practice through adequate accounting controls and to report the billing office operating results on a regular basis in a clear and concise manner.

In order to achieve these goals, it is necessary to perform a number of functions. First, to maximize receipts and minimize the number of days in accounts receivable, it is necessary that the primary responsible party receive a complete and accurate first statement as soon as possible. Also, for hospital charges, if the primary responsible party is a third-party carrier, and if the patient is to be responsible for the balance not paid by this carrier, the patient should receive a statement immediately, stating that he has incurred this charge, that his claim has been filed and that he is ultimately responsible for payment. Second, in the event that full payment is not received, follow-up statements should be generated automatically by the system at regular intervals. Third, after a specified period of time, accounts which have not been fully paid should be subjected to a system of in-house collection procedures which include preprinted collection notices or collection letters and direct telephone contact.

Finally uncollectable accounts are written off as bad debts and turned over to a collection agency in a timely manner.

OVERALL SYSTEM CONCEPTS

In achieving the above billing and accounts receivable goals, we are interested in the most efficient way of organizing and storing large quantities of data, and providing rapid access to information derived from this data. We also seek to communicate this information most efficiently to patients, third-party carriers, employees and physicians. A computer system which will be effective in accomplishing these objectives should possess certain functional properties. The basic system philosophy, the software, the hardware, the system back-up, service and cost are all important considerations.

One of the greatest advances in computer systems over the last twenty years has been that the computer's resources have been made more accessible through the development of multiple terminal, simultaneous controlled access. The speed with which processing operations are performed and the speed with which large volumes of data may be randomly accessed have made this approach practical and effective. As mentioned above, the success of a radiology billing office depends heavily upon fast access to complete and up-to-date information. The on-line, real-time computer system approach meets this need. It is feasible to provide on-line storage for all current accounts receivable and billing information and to provide an adequate number of on-line, interactive keyboard display units for those personnel who work with this information. In addition, it is feasible to up-date accounts receivable and billing information in real-time; that is, the moment information is entered. An example of the advantage of this

approach, is the patient who comes to the billing office, pays his bill and requests a copy of his statement showing this payment. Producing such a statement is easily accomplished in the on-line, real-time environment.

In considering system capabilities, software is of paramount importance. Due to the complexities and intricacies of software design, it is desirable to find proven software whose capabilities and reliability are well established. It is important that this software be flexible and easily tailored to meet individual practice requirements. Examples of the need for tailoring are in the areas of compatibility with hospital data, special third-party requirements, and differing collection policies. The system software should be well organized, systematic and well documented. The system should be easy to understand and operate and provide for complete security of the accounts receivable information.

The hardware used to implement a system is also important in that it be capable of fully implementing the desired system capabilities. Reliability of the equipment is of primary importance. Its capacity and performance should accommodate the present practice and anticipated growth, and be expandable to accommodate longer range growth. Also, it should be compatible with other systems in its communication capabilities.

Because of the importance of accounts receivable data, a secure means of back-up must be included in the system design. This should be done on a daily basis and provide a complete copy of the system in the event of a catastrophic occurrence such as a fire, theft, or equipment failure. The back-up process should include a system integrity check followed by a copy of the system on a removable media such as floppy disk, magnetic tape or

disk cartridge.

The availability of knowledgeable and responsive service is of paramount importance. The complexity of both the hardware and software are such that highly skilled, well trained, experienced system analysts, programmers and digital electronics technicians intimately familiar with the particular computer system are essential. These support personnel should have adequate back-up and support equipment at their disposal. It is also important that the service organization be well established with a history of commitment to service, and have the resources to provide ongoing support. Finally, the cost of the system should be affordable and in keeping with the benefits it provides.

SYSTEM FUNCTIONS AND CAPABILITIES

DATA ENTRY

The methods of entering data into a computer system have changed dramatically over the past several years. In the early stages, keypunch machines were used to punch data onto cards which would later be loaded as a batch into the computer system for processing. Later, key-to-tape and key-to-disk systems were devised for operation in the same manner as cards; that is, data keyed in is placed on magnetic tape, floppy disk or hard disk for later entry as a batch into the computer system. A major disadvantage of these approaches is that the operator does not have access to the resources of the computer at the time of data entry. The value of these resources at the time of data entry can be far-reaching if the system is properly designed. First, extensive editing and error checking can be performed by the computer system at the moment each data element is entered. In general, errors are most easily corrected if identified as

soon as possible. Second, and most important, full access to information stored in the data base can be provided to the operator at the time of data entry. A good example of the value of this information is in the area of payment posting. At the time a payment is being applied to an account, the operator can verify the patient's name, the patient's account number, the balance, the date of service and the procedures to which the payment is being applied.

As time-sharing, multiple terminal system designs progressed, keyboard display units were connected directly to the computer in an on-line manner and used to enter data directly into disk files within the computer system. In some system designs, these files are merely holding areas where transactions reside for later updating of the data base in a batch processing manner, as in the keypunch or key-to-tape approaches. In contrast to entering data into holding areas for later processing, it is possible to update the data base at the time the data is entered. This real-time processing approach has the advantage that all inquiries of the data base reflect the full, complete and up-to-date status of the records being examined.

In addition to the keyboard data entry methods described above, certain data to be entered may be available for transfer in machine-readable form. Common media for this transfer are magnetic tapes, floppy disks and direct computer-to-computer transfer. Direct computer-to-computer transfer may take place either over a hard wired line from one machine to another or over a telephone data communication line using modems.

In selecting which of the above data entry methods is best for a particular radiology practice, groups of data elements must be considered separately; and what is best for one practice may not be the most desirable for another. For example, we have found it beneficial to transfer patient, guarantor and third-party demographic data from the hospital in machine-readable form, however, to enter the procedures for professional fee billing through on-line keyboard display units with real-time updating. This approach has the advantage of fully automating over 90% of all data element entries while retaining full documentation control for the procedures performed. That is, procedures captured on either X-ray reports, requisitions, charge tickets or the daily log are transferred directly from the hospital radiology department to the billing office as opposed to first being processed through the hospital's business office and data processing departments. This avenue provides a valuable check on procedures performed for both the hospital and the independent radiology practice.

Accuracy of patient, guarantor and third-party demographic data and charge data is of paramount importance. Errors in address waste money in postage and generate return mail which results in added clerical costs for handling, researching the address, correcting mistakes and remailing statements. Incorrect or incomplete insurance data causes similar problems and both result in delayed payments and the cost of carrying the added accounts receivable.

It is most important that the computer system design provide as much flexibility and as many alternatives as possible for formatted keyboard entry, tape-to-tape entry, floppy disk-to-floppy disk entry and direct

computer-to-computer communications.

We next examine a number of important considerations in implementing each of the three alternatives for data entry considered above.

Keyboard Display Entry

Keyboard display terminals will most likely continue to be the predominant data entry method in computerized radiology billing systems for some years to come. Even if hospitals and radiology departments perfect their information management systems to the point that charges, as well as demographic data, coming from the hospital computer can be fully relied upon, there will still be certain data sources which will not provide data in machine-readable form. Examples are private office demographic and charge data, payments from patients and other payors, along with changes and additions to the data base initiated at random by telephone and other forms of communication.

In analyzing a system, we must be concerned with the provisions for accuracy, efficiency and flexibility.

Accuracy. In order to achieve maximum accuracy, edit checks should be made on those data elements which can be tested. Certain elements such as the street address, which can be composed of numbers, letters and special characters, cannot be edited automatically by the computer system other than noting its absence. Other fields such as a telephone number can be checked to assure that only numeric characters are entered and that a full set of digits is present. The most complete editing lies in those cases where the data entered can be directly and instantaneously compared with data held on file in the data base. An example of this is comparison of a

procedure code with its entry in the procedure inventory. One should be sure that full advantage is taken of the access to information contained in the data base and that the information seen on the screen at the time of data entry is sufficient and in a natural format which will promote accuracy.

Efficiency. Efficiency of data entry depends upon several factors. One factor is the speed of response associated with the entry of each command, data element or group of data elements. This, of course, is most important for those elements of highest volume. Another is the importance of having the data elements and their format match the data input requirements of the practice. For example, it would be time consuming and inefficient if the operator were required to tab through a large number of unused fields for a high percentage of patients entered. Next, one should carefully examine the ease of correcting errors and augmenting data, both at the time of data entry and days or weeks later, when additional or updated information is received. Certain keyboard display units possess editing features such as protected and unprotected data fields, foreground and background fields, and the ability to reposition the cursor and type over, insert or delete characters. Full advantage should be taken of these capabilities.

System organization is important in achieving efficient data entry. An illustration is in the area of creating new patient accounts and posting charges. It is particularly helpful to be able to create the account, enter all insurance information and post the charges all in a single step, without changing from one function to another. This is especially true for outpatients. Also, in the posting of charges, the system should

automatically set as many variables as possible. For example, the place of service and date of service can be automatically set. However, the ability to override the date of service easily for each procedure should be provided. In addition, during the posting of charges, the system should automatically price the charge, yet have the flexibility to allow the dollar amount to be changed.

Flexibility. Keyboard display entry inherently provides greater flexibility to adapt to changes in the hospital system than either tape-to-tape or computer-to-computer transmission. Screen formats can be designed to accommodate the various hospitals' and private offices' data. An example is to include or not include the posting of charges by physician. A change in the hospital computer system typically would not effect the keyboard display data entry software, while it might affect tape-to-tape or computer-to-computer programming and hardware requirements.

Tape-To-Tape Entry (and Floppy Disk-To-Floppy Disk)

As mentioned above, the major value of magnetic tape for data entry into the radiology billing system lies in the transmission of demographic data from the hospital. (Although tape-to-tape transfer of data also has considerable value in submitting third-party claims, this feature is considered later under "Third-party Claims" and not here.) A second use of tape-to-tape data entry is in the area of Medicare, Blue Shield and possibly third-party payments. While this form of payment transmission is not in wide use at the present time, it does hold potential for more widespread use in the future, depending upon group size.

The major advantage of tape-to-tape transmission of demographic data

from the hospital lies in the savings in clerical costs associated with keyboard entry. It has the disadvantage that today's tape transports and controllers are relatively expensive in initial hardware cost. Also, due to the complexity of mechanical and electromechanical components, their maintenance costs are relatively high. Special programs are generally required for both the hospital computer system to produce the tapes and for the group practice computer to read, edit and process the data. In deciding to implement tape-to-tape transfer, one should consider the length of time over which both computer systems will continue to be used in order to avoid redesign costs in the event that either computer is changed. Finally, the use of tape-to-tape transmission requires manual handling and the transporting of tapes. (In the case of payments from third-party carriers the packaging and mailing of tapes is also required.)

Computer-To-Computer Entry

Direct computer-to-computer transfer of information is the most sophisticated and most automated form of data transfer available today. This transfer can take place from one machine to another over direct hard-wired lines at very high speed in those cases where physical proximity permits. In those cases where the two computer systems are in different buildings, across town or in other cities, this transfer can take place over telephone data communication lines using modems. This approach has the advantages of eliminating the clerical costs associated with keyboard entry, lowering hardware costs of a tape transport and eliminating the manual transporting, handling and mailing of tapes or floppy disks. The software design costs are usually comparable to or higher than those for tape-to-tape transfer. Again, one should be sure that both systems will

remain in place for a period of time sufficient to justify the cost of designing and implementing this communication capability. It should be recognized that in those cases where substantial distances are involved, the transfer will depend upon a reasonably clear and noise-free telephone line for transmission. Effective error checking and data integrity tests are well established, and the assurance of error-free transmission is not a problem. However, in isolated instances it may be necessary to retransmit a body of material at a later time.

The major benefit of this form of computer-to-computer data entry is the transfer of demographic data from the hospital with the potential for extended use of this medium for Medicare, Blue Shield and other third-party payments.

ORGANIZATION AND STORAGE OF DATA

The major volume of data stored in a radiology billing system is patient, guarantor and third-party demographic information. Next in volume of data storage are financial transactions, made up of charges, payments and adjustments. It is the organization and storage of these data elements that we consider in this section.

It should be mentioned, however, that a number of other types of data are stored within the system. These include support files such as the procedure inventory containing procedure codes, descriptions and charge amounts; the diagnosis inventory which contains diagnosis codes and descriptions; the insurance company file and others, depending upon the requirements of the group. These basic support files are typically entered at the time of initial system set up and can be updated with additions and changes periodically throughout the year and not on a regular daily basis.

Patient Data

As each new patient account is entered, edit checks should be performed upon appropriate fields and messages issued to assist the operator in immediately correcting any errors. Upon completion of entering the account, the system should automatically organize this new account into the data base in such a way that it can be accessed at a later time through simple and logical procedures. First, it is essential that the account be quickly and easily accessible by patient name. This is due to the fact that in a majority of cases the patient name will be known, while other data elements may or may not be known. Next, it is helpful to be able to access the account by the patient's hospital account number or the patient's X-ray number. This number can be helpful in quickly referencing accounts for the posting of inpatient charges. Access by the X-ray number can be helpful on those occasions where it is necessary to refer to the X-ray jacket. During the posting of mail payments from third-party carriers it is frequently helpful to be able to post by policy number (or Medicare Number), since this may be one of the few fully specified items of information on a remittance. This will vary from state to state and from carrier to carrier. It is also helpful to be able to access the patient's account by guarantor or responsible party, or some other fragment of information such as a street address, telephone number or date of birth. In summary, each of the above methods of access will be beneficial to different practices in varying degrees.

Next, we consider the organization of inpatient accounts and the accumulation of inpatient charges prior to discharge. There are two schools of thought concerning this organization. In the first approach,

patients are entered into the computer system at the time of admission or at the time of the first radiology charge. Charges are accumulated and controlled within the computer system with billings in a "hold" status until the time of discharge. The second philosophy is based upon collecting demographic and charge data manually until the time of discharge and entering all charge and demographic data at that time. Our experience leans toward the former approach in nearly all instances - one reason being the tighter accounting controls provided by immediately entering all data into the computer system when received. In any event, it is desirable that the computer system be designed with the flexibility of accommodating either approach.

Also, patient records should be organized for fast and efficient production of insurance claims, first billings and follow-up statements.

Transaction Data

Transaction data (that is charges, payments and adjustments) should be organized for association with both patient accounts and with the accounting records. The manner in which transactions are associated with patient accounts should provide for rapid access to a detailed, itemized history display at any terminal and also provide for efficient production of itemized statements.

The updating of patient records in a real-time manner is highly desirable. For example, it can be helpful to post a payment and immediately produce a demand bill to give to the patient as a receipt, or to produce an insurance form for them to file.

Transaction data should also be organized in a manner which provides

for systematic production of all accounting reports. Daily journals and summaries, monthly reports and statistical accumulations which can be produced on demand, should not require extended processing runs for their production.

THIRD-PARTY CLAIMS

A radiology patient accounting system should, as a minimum, automatically prepare paper claims for a major percentage of the total filings with third-party carriers. The preparation of these claims should be an automatic byproduct derived from the patient accounts. As mentioned in the section on data entry, accuracy and completeness of information is fundamental in obtaining prompt payment for procedures performed. Efforts to coordinate the collection of complete and accurate source data; processing procedures which identify incomplete information and a final review prior to filing are essential elements in processing third-party claims. Either of two philosophies may be applied in identifying incomplete or inaccurate information. First, the computer system may be designed not to print the claim forms, if a condition of incomplete or inaccurate data is present. In this case, the system should produce an exception report which lists those claims which should be researched and processed immediately. The second approach is for the computer to produce those claims requiring further research as a group.

In order to obtain payments as soon as possible and to minimize the number of days in accounts receivable, a system should provide for the production of third-party claims on a daily basis. Ideally, inpatient claims should be produced immediately following discharge. In addition, however, it is desirable to have the option of producing interim insurance

claims for inpatients who are in the hospital for an extended period of time and for therapy patients under treatment. During printing, forms for major carriers should be organized by carrier. The system should be capable of carrying both a primary and a secondary insurance record and retaining this information on a long-term basis to eliminate manual filing of claims. Here, it is necessary to retain the date of filing for each claim.

We next consider the alternatives of filing claims on printed insurance forms and various machine-readable automated methods.

Paper Claim Forms

For many years, radiology groups in independent practice have assisted their patients in filing insurance claims. The majority of these claims have been processed through the use of hard-copy, preprinted forms. Many different claim forms are in use by various carriers. Production of a large number of different forms by a computer system increases the complexity and cost of the system and adds clerical cost in maintaining inventories of the different forms and the loading of these forms for printing. A great deal of progress has been made in the standardization afforded by the AMA universal claim form No. OP 409 (HCFA-1500). Until all third-party carriers possess computer systems with standardized communication protocols and data formats or standardized machine-readable media formats, it will be necessary for radiology patient accounting systems to produce paper claim forms.

Automated Claims

A significant portion of the progress which has been made in automated filing of medical claims has been in Medicare and Blue Shield programs.

Certain states have progressed more rapidly than others; however, at the present time many states are moving in this direction. There now exists a national standard format for machine-readable claims. This format is presently being adopted in a number of states by the Medicare Part B programs.

The major advantages of automated claims submission for a radiology practice are that payments are received more quickly thereby reducing the accounts receivable carrying costs, and that clerical time in handling claims is reduced. These are primarily due to bypassing the manual handling and the data input errors in the third-party carrier's processing of massive amounts of information.

Tape-to-tape, floppy disk-to-floppy disk and direct computer-to-computer communications are the most common forms of automated claims submission. At the present time, nine track, industry compatible magnetic tape at either 800 or 1600 bits per inch (BPI) is the most highly standardized machine-readable form of data transfer. While it is reliable and serviceable, it has the disadvantages of manual handling, the need for packaging and mailing, and that the initial cost of the tape transport and controller is higher than that of the other forms of equipment considered. Also, the cost of service for the tape transport and controller are usually higher than the alternative equipment maintenance costs. Floppy disk transfer is not widely used at present. This is due to the fact that not many third-party carriers are equipped to process claims using this medium. The floppy disk has the same disadvantages of manual handling and mailing as the magnetic tapes. However, costs for the equipment and maintenance are lower.

Direct computer-to-computer claims transfer provides the most fully automated form of claims submission. Manual handling is minimized, and delays in processing of mail and the need for tracing missing packages are eliminated. Computer-to-computer transfer usually provides the fastest entry into the third-party carrier's computer system, the quickest return of payments and a lower initial hardware cost. Usually, the cost of a telephone line and data set is less than the ongoing cost for maintenance of the tape-to-tape equipment. Initial software design costs are generally higher than for the other methods and one should anticipate that noise on data communication circuits may sometimes require retransmission of data.

Follow Up

The computer system should provide an effective means for following up on insurance claims which are not paid. Aged analysis reports for Medicare, Blue Shield, Medicaid and Workers' Compensation are generally the first working tool. Special reports, by carrier, of claims which were filed more than a certain number of days ago, without insurance payment are helpful. Efficient methods of handling secondary or complementary coverage upon receipt of partial payment from the primary carrier are important. Also, efficient methods of converting accounts to private-pay status following partial payment by a third-party carrier should be provided.

PATIENT STATEMENTS

An essential part of every patient accounting system is the production of statements. The computer system should be designed to produce virtually all statements, with a major percentage of these produced automatically en masse at the appropriate time for mailing. It is also essential that the system be capable of producing statements on demand at any time.

Accuracy and completeness of information is the basis for achieving prompt payment and avoiding unnecessary postage costs. For most practices, itemized statements are desirable. The preprinted statements themselves can be designed to have a professional appearance and generally have the characteristic of being quite legible. Statements should be designed to provide clear, easy-to-understand instructions, and set forth the total amount due in a prominent and logical position on the form. Most groups incorporate a description of the relationship between the separate professional fee and the hospital's charge for the technical component. Conveying this billing information as clearly and simply as possible will aid in reducing the number of telephone inquiries and the resulting clerical costs.

The system should be capable of producing either self-enclosed mailers or individualized preprinted statements suitable for mailing in a window envelope. There are advantages and disadvantages to each of these statement forms. The enclosed mailers are more costly but save clerical time in stuffing envelopes. Some groups feel mailers are less personal in appearance. Also, mailers do not easily permit additional information to be enclosed such as an assignment form, are limited in the number of itemized transactions that can be displayed without mailing two pieces of mail and are sometimes, depending upon forms design, difficult to open and work with. Most groups find it beneficial to enclose a return envelope with either the mailer or the conventional preprinted statement. To assist in applying payments received, it is helpful for a portion of the preprinted statement to be separated and returned with the payments. The computer should print the patient's name and/or account number on this

portion of the statement (and on the other portion of the statement in case an error is made in the portion mailed). Enclosed mailers are generally designed so that this information appears on the return envelope.

A very important characteristic of the billing system is flexibility in adapting to the policies the group wishes to implement. This includes the production or nonproduction of statements for specific financial classes, the frequency and timing of statements and the messages which are produced by the computer system.

There are two major categories of mass produced statements.

First Statements

In order to achieve the function of providing the responsible party with a statement as soon as possible, it is desirable for the computer system to be capable of producing statements daily. Ideally, inpatients should receive a first statement immediately following discharge from the hospital. Outpatients, emergency room patients and office patients should have statements produced immediately following the occasion of service. An exception to this rule is in the case of radiation therapy outpatients for whom charges are commonly accumulated for either an interval of time or until treatments are completed, before production of the first statement.

The system should be capable of printing an appropriate message for each financial class, explaining in very simple terms, just what the patient should expect. For example, on the first statement to a Medicare patient for whom assignment is not accepted, the following message may be appropriate:

"As a courtesy to you, we have filed your Medicare claim. Medicare will pay you directly. Please send us your check today."

Messages such as this will vary from group to group and should be easily modified by the office manager in order to implement the credit and collection policies of the practice.

Follow-Up Statements

The system should produce follow-up statements en masse automatically on a regular and systematic basis. The length of time between statements, commonly referred to as the billing cycle, usually varies from 20 to 31 days. Selection of the number of days per billing cycle will be a compromise. Too short a period will result in higher postage and statement form cost. The group may also find that patients become irritated when they receive statements too frequently. Longer intervals between statements results in delayed payments and situations where patients forget about the obligation. The system should produce appropriate automated messages for each financial class and for the number of billings which the statement represents. In addition, it is essential that the ability be provided to control the billing through account status indicators. For instance, in the case of return mail, no bill should be produced, until the address has been corrected. For a patient on a time-payment plan, statements should be produced at specified intervals with a message appropriate to the special arrangements. There will also be times when an account is placed in a "hold" status, in which case there should be no statement.

Generally, the system should produce two follow-up statements with

provisions to extend this number if desired.

Second Bills. The purpose of the second billing is to make the patient aware of the current status of his account. For private-pay patients, a message indicating that the account is past due would appear. For patients whose account was initially in an insurance pending category, the statement may indicate either a rejection by his insurance carrier, that the insurance company has not paid the claim and the balance is now due from the patient or that the insurance company has paid a portion of the account and the balance is now due from the patient.

Third Bills. This statement usually serves as the patient's final notice. Patients should receive this notice, if their account is in a private-pay status through the first and second billings with no activity on the account. Certain third-party claims, for which assignment was not accepted, would receive this bill. Also, all unpaid commercial insurance accounts which received a second bill and still did not pay, should receive the final notice. On the other hand, those accounts on time-payment plan or in a special status should not have a final notice produced. It is mandatory that the computer system faithfully and reliably carry out the broad range of billing policies which will typically vary from practice to practice.

COLLECTIONS

In order to achieve the fundamental billing and accounts receivable goals for the practice, it is necessary to identify and pursue accounts which have reached a delinquent status. The computer system can be extremely valuable in this area, both in implementing in-house collection

procedures and in working with an outside collection agency.

In setting up a system, the practice should establish a set of policies which set forth specific criteria for handling accounts on an in-house collection basis and their transfer to a collection agency. An example of such a policy is that "accounts will be transferred to the in-house collection system ten days after receiving a final notice, if no payment was received during that time." These and other similar criteria are then incorporated in the system software. In establishing such policies, it is desirable to take into consideration the standard provisions within the system for handling collections instead of establishing a set of criteria which would be costly to implement and support.

We now consider several concepts associated with in-house collections.

In-House Collection System

Practices have structured in-house collection operations either as a delinquent accounts department of the practice or as an entirely separate collection organization operating under a different name. In deciding which approach to use, one should be aware of both state and federal laws governing collection agencies. In either case, it is desirable that the computer system provide a separate means of accounting for the in-house collection operations and provide its own set of accounts receivable controls. The computer system should restrict regular accounts receivable transactions from being posted to collection accounts and vice versa.

Upon entering the in-house collection subsystem, an account should be subjected to systematic follow-up with either preprinted collection notices

or collection letters. The computer system should be capable of automatically producing these notices or letters. Experience indicates that collection notices are most effective when they are entirely different in appearance from the earlier patient statements. After these approaches have been exhausted, telephone contact is frequently employed. In order to facilitate this follow-up, the system should provide an in-house collection account work sheet which gives full demographic and transaction history detail.

In implementing the practice's policy of turning accounts over to the in-house collection system, different approaches may be followed. First, the computer system could be set up to produce a report of those accounts which have received a final notice and qualify for transfer to the in-house collection system. This list, which provides appropriate information, could be reviewed and accounts individually transferred to the collection system by the operator. A second, and more highly automated approach, is for the system to automatically convert accounts to in-house collection status and produce the first collection notice all in a single processing procedure. In either event, the ability to manually transfer accounts both into collections and back into the normal accounts receivable system should be retained.

An additional consideration is the fact that it may be discovered after pursuing an account on a collection basis, that the only method of ultimately collecting the account is to file an insurance claim. In these cases, it is helpful to have the ability to print an insurance form for collection status accounts. In addition, it is necessary that the account be easily converted to another financial class such as a time payment plan

for patients willing to make that commitment.

Collection Agency Considerations

After accounts have been pursued on an in-house collection basis and determined to be uncollectable by these methods, they should be written off as a bad debt. A clear and straightforward policy for writing off accounts is essential and this function should be performed regularly for effective management of the accounts receivable. Write-offs may be performed either manually or in a completely automated manner by the computer system. The facility for manually writing off the accounts is needed in either case. One approach is to automatically write off those accounts which have reached a certain age in in-house collection status. Whether written off automatically or manually, the computer system should provide a report for turning over accounts to an outside collection agency. This report should contain sufficient information for the collection agency to effectively work each account. The information turned over to the agency could be either in printed form or in machine-readable form such as nine-track, industry compatible magnetic tape or floppy disk.

The radiology patient accounting system should also provide appropriate accounting methods for handling those monies collected by the agency. Generally speaking, monies collected should be treated as a bad debt recovery with payments applied in a manner which appropriately reflect the collection agency performance and facilitate easy balancing of payment journals and bank deposits.

REPORTS

A desirable philosophy in the design of reports for an in-house

radiology patient accounting system is to minimize paper production by taking full advantage of on-line, multi-terminal inquiry capabilities. With convenient and essentially instantaneous access to all patient demographic, diagnosis and transaction history data, the need for printing large, voluminous reports such as a detailed aged trial balance for all patients is eliminated. The traditional accumulation of large quantities of paper in the data processing environment can be almost completely eliminated. However, a set of regularly produced reports is necessary in order to provide a complete audit trail in hard copy form. These are outlined below in the section entitled "Accounting Reports." A second type of reports, referred to as "Management Reports" are primarily of an exception nature. They single out special information or sets of accounts which require special attention. They are generally printed on demand or at intervals dictated by accounts receivable management policies.

Accounting Reports

Transaction journals for charges, payments and adjustments provide the detailed item-by-item history of all transactions posted for a day. They should provide an audit trail back to the source document which originated the transaction and provide a convenient and easy means for balancing. Since these journals will form a long-term historical record, the transactions should appear in an order convenient for later referencing and be filed in chronological order. The system should provide a charge journal for each place of service, in both totals only and order of entry form, for convenience in balancing, in addition to the order for record retention. A hash total on posting codes and the total number of transactions posted should appear to assist in balancing in those cases

where charges are not manually prepriced. As recommended by the American College of Radiology, charges should be balanced against the hospital daily log each day.

Adjustments should be authorized and carefully controlled by the manager and physicians. The adjustment journals should clearly set forth the type of adjustment, the reason for the adjustment, the authorization and amount, along with the individual who actually posted the adjustment. It is important that a free-form comment area be available at the time of posting each adjustment and that this comment appear with each adjustment on the journal. These journals should be prepared in a form and stored in a manner that will enable easy review.

A payments journal should be provided that facilitates the centralized application of mail payments. In addition, a separate time-of-service payments journal should be available for each different place of service. As in the case of adjustments, a free-form comments area should be provided which fully documents the source of payment. (For example the payor and check number.)

Next, there should be a report which summarizes the detail in the various journals and automatically updates all accounting records. The current day's charges along with month-to-date and year-to-date accumulations should be provided. Payments and adjustments, by type, for the day with month-to-date and year-to-date accumulations and the current accounts receivable status should also be provided. In effect, this report provides a snapshot of the entire practice at a particular moment in time.

As such it should provide a means for viewing each place of service separately as well as viewing the practice as a whole. In addition, entries of daily totals for charges, payments and adjustments should be automatically entered in control accounts. These control accounts then provide a complete chronological history of all daily transaction totals.

The above set of accounting reports provides a complete audit trail for all transactions. In addition, a comprehensive set of internal testing and selfbalancing software should be provided along with a tightly controlled and efficient back-up system. All of these elements are necessary to assure the security of this valuable set of accounts receivable information.

Management Reports

We now consider those reports whose purpose is to assist in management of the accounts receivable and in management of the practice as a whole, as opposed to providing accounting controls.

The reports which deal with the accounts receivable should provide an overall picture of the age and status of the receivables and then permit identification of specific accounts requiring special attention. An aged analysis report in summary form which breaks out each financial class is an extremely helpful tool in evaluating the accounts receivable status overall. Upon study of this report and identification of those areas requiring further attention, the manager should have the ability to list a specific group of patients by age category and financial class, with sufficient information for follow-up. In some cases, it is also desirable

to limit consideration to patients whose balances fall within a certain range.

A number of special exception reports have proven to be beneficial in follow-up of third-party claims. These reports should contain the information necessary for follow-up without the need for reference to the patient's account. Examples of these reports are Medicare and Medicaid exception reports which list unpaid accounts which are over a certain number of days old. Another example is a listing of Medicare accounts, with complementary Medicaid coverage, for which a Medicare payment has been received 45 or more days ago, without a Medicaid payment.

Another group of important management reports lists patients which have been placed in a special status. Examples are those reports that list patients in a no-billing status which are over a certain number of days old and those that list return mail accounts for whom a valid address has not been found and billing has been suspended.

It is possible to automate the handling of credit balance accounts and the preparation of refund checks. First, a credit balance report is produced, giving a detailed transaction history for each credit balance account. This provides the information for review and authorization of refunds. Next, the fully automated refund system enables the selection of accounts for refund, automatically posts the refund adjustment and produces the refund checks along with a fully documented check register.

In order to minimize clerical time and apply write-off policies uniformly, a number of automated write-off reports may be implemented. These include a small balance write-off report, a collection account

write-off report and a return mail write-off report. Each account included must meet a specific set of conditions and in order to fully review all amounts written off, a detailed history of all transactions on each account should be provided.

In addition to the above reports for accounts receivable management, a number of general practice management reports should be available. These include an analysis of charges which gives a breakdown of revenue generation by department and specific procedure, a referring physician report which provides the source of referrals and resulting revenue generation by place of service and a production report which provides charges by physician.

RANDOM ACCESS TO INFORMATION

During a typical working day, a number of situations will occur at random which can be handled most efficiently by accessing information stored within the computer. A good example is a patient calling or coming into the billing office about a statement he has received. Although a well designed system will minimize inquiries by clearly explaining the services received and payment procedures to be followed, a certain level of questions is inherent in all radiology billing operations. The ease and speed with which the desired information can be accessed is an important consideration and it is essential that the information be complete and fully up to date. In some cases, it may be necessary to display or print information, while in other cases, it may also be necessary to add or change data elements within the data base.

Some examples of common patient questions that can be handled by

simple inquiry and display are:

> "I have paid the hospital for my X-ray exams. Why have I received a bill?"
>
> "Haven't you received payment from my insurance company?"
>
> "Didn't you file my insurance claim? When?"
>
> "I have received your statement saying that my account is delinquent and that I will be turned over to a collection agency. I don't believe that I have previously received statements from you."

In answering the first two questions, it is necessary to have immediate access to the complete, up-to-date charge, payment and adjustment history. In the third and fourth instances, full access to patient and insurance demographic information, along with the billing history, is essential.

Common patient calls which involve the production of printed material are:

> "I would like another copy of my statement showing that I have paid this bill in order to file my insurance."
>
> "I would like a copy of my statement showing that I have paid this bill for income tax purposes."
>
> "I misplaced the statement you sent, could you send another copy?"
>
> "I received your statement saying that you had filed my insurance claim, and that the insurance company has not paid. I called my insurance company and they say they have no record of the claim. Could you send the insurance company another copy of the claim?"

In each of these cases, billing office personnel should be able to quickly print a statement or insurance form on demand. When requesting a demand insurance claim, the operator should have the option to select all or specific charges for inclusion.

Several common patient calls which involve adding or changing data within the system are:

> "You have billed me for X-ray services. When I was in for my exam, I did not have my insurance records with me. I do have insurance coverage and would like for you take the information about my policy and file a claim."
>
> "I have received your statement and cannot pay this amount in full. Could I make regular payments each week?"
>
> "I paid the amount you requested. Also, I checked with my insurance company and they say that they sent a check to you. Would you please refund my payment?"

In the first instance, it is necessary to add insurance data to this patient's account and produce a demand insurance form. In the second case, the account's financial class should be changed to a "time-payment plan" and the payment arrangements should be recorded with the account. In the third example, immediate access to the account's payment history is necessary in order to discuss this with the patient. A note on the account concerning this conversation is helpful when review and authorization of the refund is performed.

The above illustrations involve access to individual patient accounts. It is also essential that management reports encompassing information on groups of accounts be available on demand. An example is the listing of a group of slow-pay accounts in a particular financial class for follow-up.

ADDITIONAL APPLICATIONS

The primary function of computer systems in independent radiology practice considered here is the handling of billing and accounts receivable operations. However, the computer system can be initially designed or

subsequently expanded to accommodate a number of useful and beneficial functions. Some of the most common additional applications incorporated in radiology systems are the following:

Teaching File

X-Ray Jacket Retrieval

Clinical Information for Therapy Patients

Appointment Scheduling

General Ledger

Pension and Profit Sharing

Accounts Payable

Payroll

Word Processing

Departmental Management

In studying system capabilities, the availability of software modules for the additional applications which are most appropriate and important to the practice should be considered.

A MICROCOMPUTER SYSTEM FOR EMERGENCY WARD RADIOLOGY "WET READINGS"

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ABSTRACT

A microcomputer system is used by radiologists to create short reports on emergency ward radiology studies. This report is then immediately produced on a remote computer printer in the emergency ward.

INTRODUCTION

Rapid transmission of radiology "wet readings" to the Emergency Ward or to any other critical care location is essential for efficient patient management. Commercially available systems for allowing the transmission of "wet readings" reports includes manual systems such as a phone call or a written report transferred by a messenger or a more automated technique such as the Tele-Autograph (fascimile transcriber. The former technique requires more time and requires both a participant at the origination site and the distribution sites. The Tele-Autograph system is commonly used and this generates a hand-written fascimile at the receiving site. Problems with the Tele-Autograph system includes legibility, maintenance, and the limitation of one distribution site. In an attempt to solve these problems, the authors set out to design and implement a system which utilizes low-cost computer technology which is available "off-the-shelf". The system would provide rapid transfer of "wet reading" reports, rapid generation of messages by having stored phrases and reports within the computer, guaranteed legible messages by having the message printed on a Lintz printer at the site of utilization, computer addition of time and dates to the printed reports for added documentation, and allow the system to be upgraded to handle a minimum of three separate distribution (printing) sites.

MATERIALS AND METHODS

The availability of low-cost, integrated computer systems allows for implementation of the projects goals. The hardware system that was chosen includes a Commodore Business Machines' (CBM) 4016 computer and a CBM 2022 printer. This system was chosen because of its low cost, its fully integrated computer, keyboard and video screen, and the local availability of maintenance by numerous retail outlets. The unit is self-contained and is about the size of a standard CRT terminal. Printers can be attached to the system through the IEEE-488 standard bus.

The CBM computer is based on the 6502 microprocessor. The CBM 4016 computer contains 16 Kbytes of on-board random access memory (RAM). The BASIC language is available on-board in ROM (Read Only Memory) and the application program is loaded through a cassette tape recorder into the random access memory. The 6502 microprocessor runs at 1 MHz.

The computer has been modified so that the "RUN/STOP" key on the keyboard and the "ON/OFF" on the computer are disabled so that the program cannot be interrupted and the machine cannot be turned off without removing the plug from the wall.

The CBM 4016 computer that was used in this implementation has the added advantage of 14 keys on the top row of the keyboard used by the computer for special characters and graphics. Utilizing the shift key, this allows 28 separate keys which can be used by the programmer to select a predetermined report or message. The program was written totally in ANSI standard BASIC. The program was optimized for speed so that the limitations of BASIC are transparent to the user. The program runs in a continuous loop evaluating the keys pressed on the keyboard to input a message or signalling other functions. Users enter a message as formatted and queried by the computer which includes the name,

identification number, patient location, radiologist's initials, and a report. The report can be generated either by typing the full message or by selecting pre-programmed words or phrases by a a single key stroke.

Other functions that the program contains is looking for reset (erasure) of the current message, to print the message out at a particular location, or to give the user instructions as to how to use the system. When the user indicates to the computer that the message should be printed, the program then formats the message to conform to the selected paper size on the printer and adds the date and time to the report generated.

As mentioned above, the computer internally stores a description as to how to use the program. Since the computer is located within the Emergency Room and there is a rapid change of staff, the computer acts as its own instructor and thus requires minimal additional supervision to instruct users as to how to use the system.

DISCUSSION

The system as designed has been in operation daily since December of 1980. The computer runs 24 hours a day and during this period of time the computer has required maintenance on two occasions. On both occasions the computer could be repaired at a local retail store in less than 12 hours.

A large number of resident and staff radiologists have used the system which is itself testimony to its usability. The Emergency Ward personnel are extremely satisfied with the legibility of the reports and the added reliability over the previous Tele-Autograph system.

The complete cost of the system, including software development, was $1,655 (list price). When the cost of the previous Tele-Autograph system is considered

the payback time for the microcomputer system is 3.5 years. This time can be shortened because of the reduction in "off-the-shelf" computer systems. The microcomputer system has the added advantage of allowing for expansion of the prinout sites
to a maximum of eight. These printers can be separated by as much as two hundred feet and thus the radiologist can select a particular site within the hospital or emergency setting to print out the message.

A MICROCOMPUTER APPLICATION TO RADIOLOGY INSTRUCTION

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Due to the large amount of data that a radiologist must deal with relative to maintaining his scientific competence as well as data relative to his day-to-day practice, some means of organization of this material is imperative. To date the radiologist has depended primarily upon his own memory in recalling pertinent literature to a particular case under consideration or with regard to prior cases with similar radiographic findings. In an attempt to organize such data such that retrieval is more efficient and accurate multiple means have been suggested and implemented. The indices of the various radiologic journals are of great assistance in retrieving relevant information as long as the appropriate journal can be consulted. Often times, however, the content of an article may be remembered, but the location of the article cannot be recalled. With regard to prior patient material most radiologists rely primarily upon their own memory or upon somewhat inadequate personal filing systems.

Many radiologists have attempted to cope with the organization of data by implementing mechanical filing systems for both interesting cases and pertinent journal literature. Institutions which have access to large computer systems have used these computers in some form or another in a similar attempt to organize a large data bank. Even those

institutions which have access to a CT scanner have been prompted to use the associated computer as a file management machine. Almost all systems which have been described use some form of coding system for the retrieval of both literature and patient material. Many of the systems are based on the ACR anatomic and pathologic codes. While this is indeed universal in nature it offers many difficulties due to the need to individually code each particular patient report or journal article.

The system presently described uses a relatively inexpensive home microcomputer for the purpose of patient and reference material retrieval. The software developed by the author allows both storage and retrieval of this material using a keyword entry system.

In addition, the same software has been modified for the development of an interactive teaching system using video material taken from a CT scanner monitor.

SYSTEM DESCRIPTION

The system used consists of an Apple II Plus microcomputer with 48k of random access memory and two 5¼" floppy disc drives. Video output is obtained from an inexpensive 9" black and white monitor connected to the computer video output port. An alternative to the video

monitor is the use of a commercial television set coupled with a commercially available battery operated RF converter connected between the output port and the TV tuner. The entire system can be purchased for less than $2,500. With the addition of a printer and printer interface card copy can be generated from the stored patient records and journal literature if this is considered necessary.

Additional hardware is necessary for the interactive teaching program using videotape material. The additional hardware includes a one-half inch VHS format videotape recorder which has solenoid controls and which outputs the video control tract so that this can be computer monitored. A second 9" black and white monitor is also used for display of the video material and interface board which fits into the Apple buss is used for monitor and control of the videotape recorder.

The program which was developed for the library management function was designed on a keyword retrieval concept. The justification for this design was based on experience and literature evaluation of other coding and non-coding systems as they pertain to larger systems.

One such system involves the use of free text search of all materials stored within the core of data. The use of a free text search scheme limits the versatility of

is still somewhat rigid. It is however, more readily expandable than other systems and certainly more humanly engineered.

The program developed for this system uses free keyword entry which is a simple method of keyword indexing. It was felt that simplicity was an attribute of primary importance in any personal system of file support. It was felt that allowing unstructured keyword entry into the system allowed the greatest freedom of access and therefore would create a maximization of physician usage. The advantages of literature dissemination are negated if data is not readily at hand or easily retrievable. Since any keywords may be entered into the structure the system responds readily to changes in the radiologic field as well as to changes in the interest or experience of the individual or group of radiologists involved. It may be argued that the absence of a strict hierarchical structure will lead to lost information or excessive redundancy. It is felt that with a relatively small group of individuals using the system a sufficient degree of consistency will be maintained within the keyword file structure.

FILE STRUCTURE

The keyword file is kept as a separate file on a single disc and is used to access the record file which contains record specific information. The keyword file is a

the small system user, since the entire text of the article or a significant portion must be entered into the computer in order to use this system. Also the sequential search of all entered material for specific user requested words involves an enormous amount of time even for rapid processing machines. Such a method is also unwieldy because synonyms and syntactical variety lead to the retrieval of unwanted articles and lack of retrieval of a significant number of desired articles. For this reason some form of coding system is almost always used.

Numerical and letter codes while logically well developed are somewhat difficult to use. They must be memorized or an index must be always available. They also suffer from the fact that they are relatively rigid structures. They are non-uniform in their hierarchial structure, varying with the expertise and diligence of those composing them. They also suffer from the fact that they are not readily expandable. In some cases, a code may be more easily adaptable to either the classification of journal literature or the classification of radiographic cases. The strength of coding systems lies in the often well developed tree structure which has been implemented to allow one completeness of reference or case material retrieval.

The use of a fixed keyword system such as the Medlars retrieval system offers a simpler approach, but one which

sequential file which contains an alphabetic listing of all keywords entered into the system. Along with each keyword is stored the sequential list of all record numbers referenced by that keyword in the order of the record entry.

The record file is a random access file with each record consisting of 256 characters.

The system allows the entry of up to nine keywords per article or patient record. In addition, up to ten records can be concatenated for storage of a single entry. This allows for a total of 2,560 characters to be entered into each record.

In the case of record retrieval the user is allowed to enter up to four keywords for this function. Prior to entering the words the user is allowed to consult an alphabetic listing of all keywords within the system. If the user enters a keyword which is not listed within the source, the user is prompted for a substitute word. Upon completion of keyword entry the user may combine the keywords with the use of boolean operators for the purpose of searching the record file. After the desired sequence has been selected the records indicated by the search are outputed either to the monitor screen or to a printer.

The program is entirely menu driven and takes no computer

expertise on the part of the operator. This system is presently being used to store the impressions of the reports on CT body cases.

In addition, selected case material has been accumulated on a videotape using the video output of the CT scanner console. The text material related to each case is entered into the system using the same keyword file structure as described above. The videotape frames corresponding to each image associated with the case are then appended to the record file for that particular case. When the record file is retrieved the operator then has the option of reviewing the videotape frames associated with that particular case.

CAI APPLICATIONS

Only slight modifications of the program were necessary in order to make the system into an interactive instructor. Each lesson is designated as a separate keyword and each question within the lesson is designated as a separate record. Therefore each lesson may have multiple questions which relate to that particular lesson. Since each question is delegated a record number the videotape images which are relevant to that question may be appended in the same manner as described above. A running record of the number of correct answers is kept as the student progresses through a single lesson. At the end of the lesson the final question

contains pointers to appropriate branches based on the number of questions answered correctly.

The pointers which were used are themselves lesson numbers and are subsequently used as keyword entries into the system. Again, a number of questions may be associated with each lesson and subsequent pointers to further branches can be placed within the last record. In this manner multiple lessons can be placed into the record file and varying combinations of lessons can be assembled when making a teaching program. The change is accomplished simply by placing alternative pointers within the final question.

USE OF A MICROCOMPUTER IN OBSTETRICAL ULTRASOUND INTERPRETATION:

THE OBUS SYSTEM

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ABSTRACT

A microcomputer system known as OBUS has been designed as an aid to the practicing physican ultrasonographer in the measurement, calculation, and reporting of obstetrical ultrasound examinations. The system automates many of the routine, repetitive tasks of the examination process. At the same time it provides capabilities for fetal gestational stage and weight estimation and growth assessment, not otherwise readily available, but essential to thorough and complete evaluation of fetal and maternal status. The system has been in routine use for two years in our hospital and has become an integral and essential part of the examination process. OBUS is illustrative of the kinds of uses of microcomputers we can expect in clinical medicine in years to come, in which direct and personal interaction between the physician and the computer occurs.

INTRODUCTION

The direct use of computers by physicians in the analysis and interpretation of radiologic examinations has been a relative rarity, with the exception of dynamic nuclear

medicine imaging, CT scans, and digital angiography. As microcomputer systems become ever more cost effective, powerful, and versatile, however, a growing number of such applications can be expected.

Obstetrical ultrasound offers an ideal opportunity for integration of the computer into the analysis and interpretation process. This paper will describe an application of the microcomputer system known as OBUS to the measurement and calculation of fetal parameters, assessment of fetal status and growth analysis, and reporting, filing, and retrieval of obstetrical ultrasound examinations. In this system, direct physician/computer interaction is required as an intrinsic part of routine practice.

Motivation for development of OBUS has been the repetitive and time-consuming nature of many of the tasks involved in the ultrasound examination process. The assessment of fetal stage and weight and growth analysis are among the most important aspects of obstetrical ultrasound, since IUGR is often clinically silent, only detectable by means of ultrasound, yet is one of leading causes of antenatal and neonatal morbidity and mortality.[1] Tedious measurements must be made, using hand-held or electronic calipers,

calculations performed, normal ranges looked up, and gestational ages expected on the basis of clinical dates determined. Measured and calculated quantities must be transcribed multiple times (into a calculator, into a logbook, into reports). A report must be generated, containing detail about fetal number and position, activity, heart beat, respiratory movement, organ survey findings, amniotic fluid volume, and placental position. Despite such detail, many such examinations are normal, and the reports tend to be highly stereotyped. The OBUS system is designed to facilitate performance of all of these tasks.

SYSTEM DESCRIPTION

The OBUS system has been implemented on an Apple Computer and requires two floppy disk drives, a video monitor, a special input device called a digitizer, or graphics tablet, and a printer. The digitizer consists of a 12" x 12" translucent, flat surface which is electromagnetically charged, and a hand-held cursor with an electric pick-up coil, which can be used by an operator to designate to the computer any artibrary point on the digitizer surface. This can be used to quickly trace curves, select points between which measurements are desired, designate functions to be performed by the computer, or choose phrases to be assembled

into a radiologic report. The translucent surface can be illuminated from below, so that multiformat transparency ultrasound images can be visualized while being measured on the digitizer.

OBUS is used to perform the following tasks: (a) patient examination login; (b) fetal parameter measurement; (c) gestational age and weight calculation; (d) growth analysis; (e) data filing; (f) interpretation; (g) physician signature; (h) report filing; (i) report printout; (j) inquiry; (k) daily log production; and (l) generalized file search.

Use of OBUS speeds up the entire process of interpreting and reporting of obstetrical ultrasound examinations, reduces physician and ancillary manpower requirements, eliminating many tedious routine tasks, and provides analytic and calculation capabilities not otherwise available for assessing fetal growth and development. Calculation of gestational age and weight are based on regression formulae developed from empirical and published data.[2] Growth analysis is based on percentile of weight compared with population ideal weight.

DISCUSSION

The OBUS system has been enthusiastically adopted for virtually every examination in our Department by staff, fellows, and residents doing ultrasound. Substantial benefits from use of the system have been immediately perceived, and the system has become an essential part of routine practice. In addition, we were surprised to find that availability of the computer has stimulated several physicians to use it to teach themselves introductory programming.

Other potential applications of this kind of system are in echocardiography, and in carotid artery real-time and Doppler scanning. In these areas, measurement and calculation must be performed as a prelude to interpretation. While use of a digitizer and computer to generate reports for other less measurement-intense examinations is also possible, the rationale for computer use in such situations is less compelling. Nonetheless we have been impressed with the ease with which the digitizer tablet is used as a physician/computer interface, for menu command selection, and for text generation, much as has been attempted with the SIREP and various other approaches to computer-based radiologic reporting. We believe that the digitizer may

represent a useful approach to reporting, particularly in situations where the entire range of choices can be laid out on a single overlay.

The OBUS system has been designed to run entirely in a stand-alone mode. However, it can also be linked with a radiology departmental computer, for centralized registration, filing, and reporting of examinations.

The economics of using a system such as OBUS are attractive for several reasons: (a) use of OBUS reduces professional as well as clerical manpower requirements; (b) the computer can be used for a wide variety of other purposes for which packages are available, including word processing (for correspondence, manuscripts, insurance forms, etc.), patient billing and accounting, medical education, computer-aided diagnosis (e.g., Lodwick's bone tumor diagnosis program[3]), access to information utilities, recreational programs, data base management, and many others; (c) entire system cost is on the order of $10,000.

Such uses can be expected to increase steadily as an ever growing number of well-designed packages becomes available for supporting the practice of medicine as well as for improving the efficiency and effectiveness of clerical and

business office functions. The major point that should be recognized is that this discussion is no longer about the future of computers but about the present. The capabilities we describe are not only available, but eminently affordable. Indeed, in ultrasound, as in radiology in general, the inroad of the computer is inevitable and inexorable. The forward-looking practitioner cannot afford not to learn to take advantage of its capabilities.

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FIBER OPTIC NETWORK WITH IMAGE STORAGE AND DISPLAY SYSTEMS

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Background

Any reasonably large radiology department, especially those performing over two hundred examinations daily, has problems with the storage and retrieval of radiographs and other images. Although management systems utilizing bar-code reading light pens to track x-ray folder movement have substantially improved retrieval, there still are considerable personnel and space resources required to maintain and handle these files. In most academic institutions, in particular, there is the additional problem of referring physicians desiring these films in their private offices, on the floors, in the operating room (OR), in intensive care units (ICU), or in conferences.

Previous similar examinations must be retrieved for comparison whenever a patient has a new exam. Also,the same patient may have several examinations on the same day or within a few days. Often these examinations are ordered by different physicians all of whom may wish to review the films essentially at the same time in different parts of the hospital. In addition, there is a problem with the time it takes to deliver films from radiology to such areas as the OR or ICU where they are sometimes needed immediately.

There are several modalities in radiology which already produce digital images. Nuclear medicine, computerized tomography, positron emission tomography, nuclear magnetic resonance, ultrasound, and digital

fluorography create digital images. Although, as will be shown later, the majority of the images are still in radiographic form, the percentage of images which are digital is increasing continuously.

The cost of digital storage has continued to declined at a dramatic rate. Laser optical disks are now becoming available which will even further substantially reduce the costs of digital storage and, therefore, for the first time make digital storage of radiographic images a reasonable possibility. With increasing volumes of work in our department, with the increasing percentage of digital images, with the decling cost of digital storage, and with our development of communication protocols for the digital fluorography unit, we have seriously begun the development of an image storage and retrieval system as will be described below.

System Specifications

As we began our planning for the imaging network, it became obvious that we had to plan for the long-range needs in order not to have to change course after investing considerable resources in a system we would quickly outgrow. There are three aspects of the system which should be carefully analyzed: acquisition, storage, and display. In order to analyze these three major areas, one must carefully look at those components already in place such as in computerized tomography where there already exists acquisition, storage and display components although the display system may not be ideally suited for other

modalities. The same argument holds true for ultrasound, nuclear medicine and digital fluorography and, in fact, anywhere there is already digital processing there is likely to be a reasonable display system. Such factors as the required image size and resolution, the necessary transfer rates in order to produce images at a reasonable rate, the distances required between system components, costs, and reliability all must be considered in the specifications.

Acquisition Systems

Table 1 shows the image acquisition requirements for the various sections in our department. SPF stands for single or standard picture frame which consists of 512x512x8 bits; this SPF equals 262, 144 bytes or 2.1 megabits per image. As indicated in this table, we have assumed a 1024x1024 spatial resolution, consisting of 4 SPF's, is sufficient for general radiographs. Certainly a chest radiograph has a resolution in the neighborhood of 2000x2000. However, this imaging network is designed for review and comparison purposes and is not designed for initial interpretation. Therefore a 1024x1024 resolution is considered ample and actually may only be required in special circumstances allowing most images in the long run to be stored and displayed in 512x512 resolution. You will note that in our department one-seventh of the images are currently digital although these images represent half of the sections of the department. Also please note that nuclear magnetic resonance is not included since it is only now being installed in our department and is not yet clinically operational. Table 2 indicates the

TABLE 1

IMAGE ACQUISITION REQUIREMENTS

Section	Exams/Yr	Averages Images/Exam	SPF's/ Image	SPF's/Hour Avg.	SPF's/Hour Peak	Already Digital?
GI	12,403	20	4	480	800	No
GU	3,408	14	4	112	160	No
Ortho	30,318	5	4	300	480	No
Chest	60,224	3	4	360	480	No
Angio	2,979	30	4	180	240	No
Neuro	5,583	40	4	480	600	No
CT Head	8,246	30	1	70	100	Yes
CT Body	1,864	50	1	50	100	Yes
Ultrasound	5,388	50	1	125	200	Yes
Nuc. Med.	7,608	12	25	12	15	Yes
Dig. Fluoro	2,000	45	1	45	90	Yes
TOTALS			Already Digital	302	505	5
			To Be Digitized	1912	2760	5
				2214	3265	

locations and the acquisition hardware utilized for each of these areas. The digitization of radiographs will occur in four locations as indicated Table 2. Based on the data in Table 1, 690 images must be digitized during each hour at peak times. Each of these images consists of four quadrants, each representing 512x512x8 bits to create a total

TABLE 2

IMAGE ACQUISITION DISTRIBUTION

Location	Building	Computer or Interface
Ultrasound scanners (5)	Dulles Gr N	DeAnza-LSI-11 and CT computer below
CT Scanners (3)	Dulles Gr N Dulles Gr S	Data General Eclipse
Diasonics digital fluoro	Dulles Gr S	PDP 11/23
DeAnza digital fluoro	Courtyard Gr	DeAnza-LSI-11
PETT Scanner	Donner 3	Perkin-Elmer
Nuclear Medicine Cameras (5)	Donner 3	Gamma-11 PDP 11/34
Cardiac N.M. Camera	Ravdin 7	Gamma-11 PDP 11/34
X-ray dig.-fileroom (2)	Dulles Gr N	DeAnza - PDP 11/23
X-ray dig.-GU/ER (1)	Courtyard Gr	
X-ray dig.-out pt. (1)	Silverstein 1	

Fiber optic lines needed - 8

image of 1024x1024x8 bits. We have decided that it is easier and less expensive to create one additional image at low resolution for storage in addition to the four quadrants than to attempt a high resolution scan with interpolation down to a lower resolution image later.

It is assumed that each image will take approximately 15 seconds to digitize and therefore each of the four units can handle approximately 240 images per hour which is more than ample to handle the peak loads of the department. At each of these digitization stations, there will be a bar-code reading light pen attached to the CRT for patient identification, linked to the radiology management system currently in use.

Figure 1 shows a diagram of the digitization system which includes the four stations described. Each of the units will have a video camera, which is a standard 525 line system mounted over a standard viewbox. On this standard viewbox will be a movable platform to allow the rapid movement of the radiographs of different size in order to capture each quadrant quickly and accurately. The camera's electric zoom lens will be modified to automatically adjust to the proper size image in each case. A DeAnza image array processor will be used with inputs from all four camera systems which is, in turn, linked through a Digital Equipment Corporation (DEC) PDP 11/23 which is attached to the communicator through the fiber optic cable. This portion of the network will be described later. Although many of the capabilities of the DeAnza Image Array Processor are not required for this application,

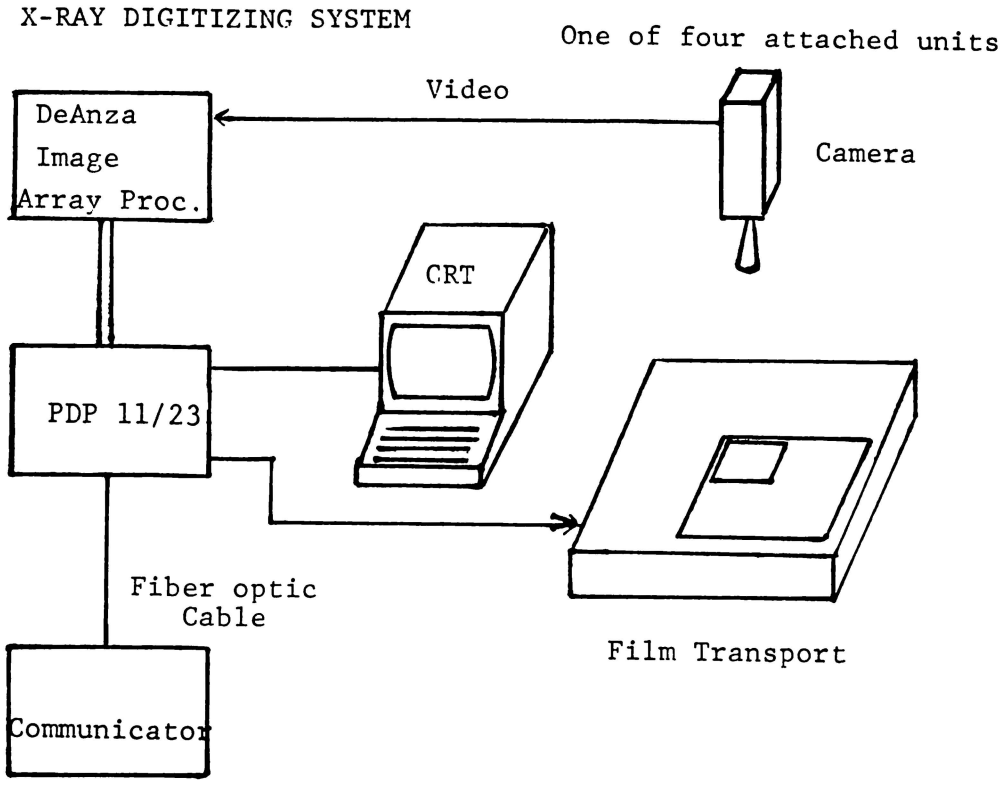


Figure 1

other projects will more fully utilize its pipeline processing functions.

Image Storage

Table 3 shows the image storage requirements for our department per year. This table for simplicity assumes no growth and no new modalities and simply shows current activity. These 4.4857 x 10^6 SPF's per year translate into 9.407 x10^{12} bits per year. We are currently storing our images for 10 years which would therefore require 9.407 x10^{13} bits. If one assumes that a ten-fold data compression could be achieved which is probably reasonable, this reduces the storage requirement to approximately 10^{13} bits. Although chest radiographs really cannot

TABLE 3

IMAGE STORAGE REQUIREMENTS

Section	Exams/Yr	Average Images/Exam	Images/Yr	SPF's/Yr
GI	12,403	20	248,060	992,240
GU	3,408	16	47,712	190,848
Ortho	30,318	5	151,590	606,360
Chest	60,224	3	180,672	722,688
Angio	2,979	30	89,370	357,480
Neuro	5,583	40	223,320	893,280
CT Head	8,246	30	247,380	247,380
CT Body	1,864	50	93,200	93,200
Ultrasound	5,388	50	269,400	269,400
Nuc.Med.	7,608	12	91,296	22,824
Dig. Fluoro	2,000	45	90,000	90,000
	140,021	12.4	1,732,000	4,485,700

tolerate compression beyond 8 bits of grey level, many other radiographs have much less stringent demands on latitude or have large portions of a rectangular shaped film which are not used. Therefore a ten-fold data compression is probably reasonable.

If these ten years of images were to be stored on conventional magnetic disks, such storage would require 10,000 five hundred megabyte disk drives. Obviously, this is not economically feasible or perhaps

even possible with current controllers. However, there are several manufacturers announcing laser optical disks which will be on the market in the next year or two. These laser optical disks contain 10^{11} bits on a single platter. Jukebox designs have been presented which contain 10^{13} bits which is probably sufficient for the image storage needs of our department.

Image Display

Radiologists as well as other physicians are accustomed to having multiple images simultaneously available for their review mounted on multiple viewboxes. It is not practical to consider having multiple display monitors in configurations similar to how viewboxes are now utilized. In our department, for example, there are over 5,000 single viewbox units, if the multiviewers are included. For the design of this network, we have assumed that each display will consist of four monitors and one CRT. It is likely that there will be situations where fewer monitors are needed and others where more are required. If these monitors can be further subdivided by allowing four images to be shown in the four quadrants of the monitor in low resolution for a quick viewing, having four monitors may be quite ample. Only experience with the system will determine how acceptable these arrangements are, but one important consideration is the transfer rate that the display system can handle. These limited number of monitors will only be acceptable if multiple images can be displayed rapidly with easy control by the operating physician.

TABLE 4

IMAGE DISPLAY DISTRIBUTION

Location	Building	Number Units
Ultrasound/CT reading room	Dulles Gr N	1-2
Active Fileroom	"	1
Conference Area 1	"	1
Conference Area 2	"	1
Student Conference Room	"	1
Chest reading room	"	2
Neuro reading room	Dulles Gr S	1-2
GI reading room	"	2
GU reading room	Courtyard Gr	1
Ortho/ER reading room	"	1-2
Angiography reading room	"	1
Neuro-angio control room	"	1
Outpatient Reading Room	Silverstein 1	1
Nuclear Medicine reading room	Donner 3	1
Donner Auditorium	Donner Basement	1
B-14 Conference Room	" "	1
Cardiac Nuclear scanning	Ravdin 7	1
	Total Units	19-22

Additional features of the display system will include the ability to "zoom" or look at one of the quadrants of the 1024^2 image and, therefore, be able to resolve on a 525 line monitor the 1024 matrix

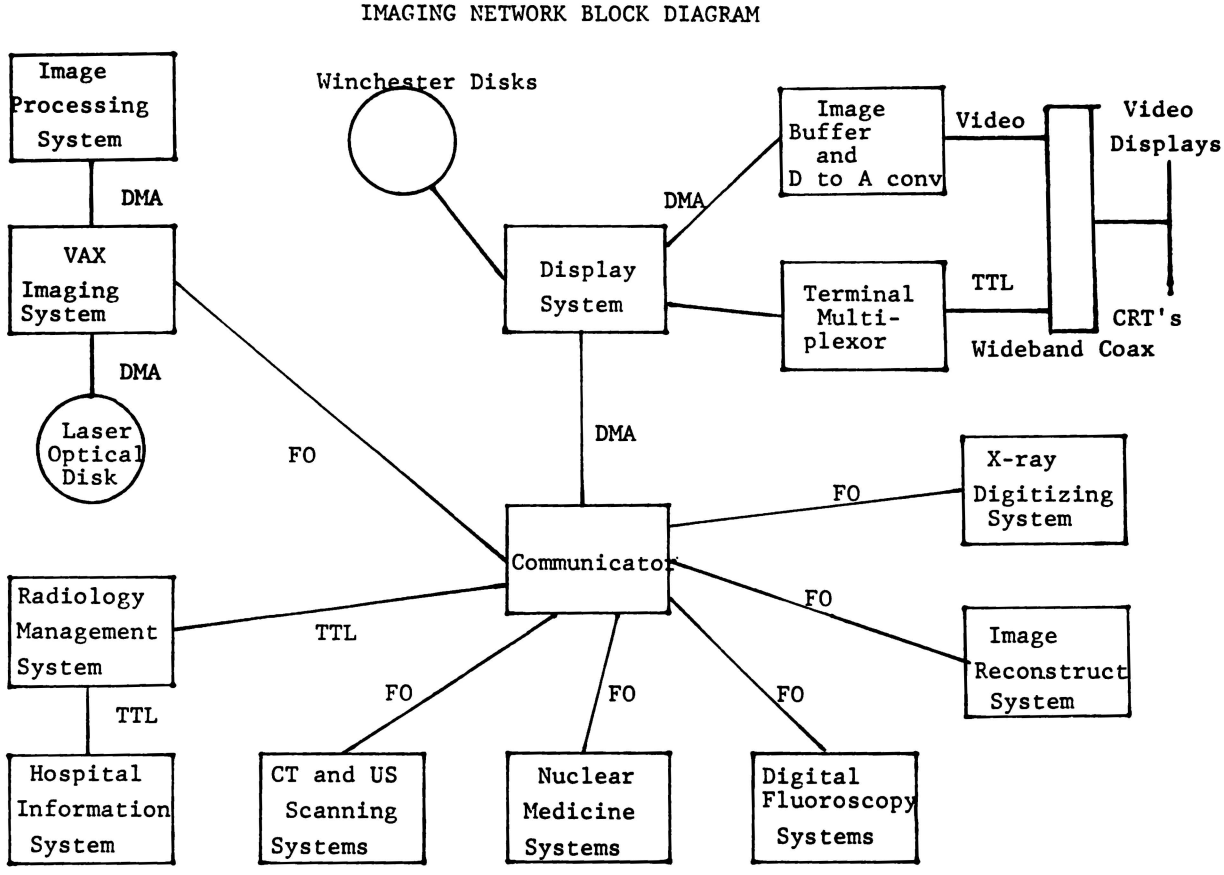


Figure 2

resolution. In addition, one should be able to pan around the image or scroll to look at all four quadrants with simple cursor key control.

Table 4 shows image display locations and the number of units required at each location, each unit consisting of four monitors and CRT.

Network Configuration

Figure 2 shows the block diagram of our planned imaging network. This network will consist of both the fiber optic links and a wideband

TABLE 5

NETWORK EQUIPMENT REQUIREMENTS

Device	Number	Unit Cost	Total Costs $1000's
Display video monitors	88	500	44
Display CRT's	22	1000	22
Digitizing DeAnza	1	80,000	80
Digitizing CRT's	4	1000	4
Digitizing Pen readers	4	1000	4
Display system	1	250,000	250
Communicator	1	250,000	250
Imaging system	1	280,000	280
Laser Optical Disks	1 Jukebox	500,000	500
Fiber optic boards	10	2000	20
Fiber optic cable	3800 ft.	1 / ft	4
Coaxial interfaces	220	2000	440
Coaxial cable	800 ft.	5 / ft	4
Display Image buffers	88	4000	352
		TOTAL	2304

coaxial system. The configuration of this network takes into consideration the transfer rate requirements for both acquisition and display. The average hourly acquisition rate required is 2,214 SPF's or 1.29 megabits per second. The peak hourly acquisition rate is 3,265 SPF's or 1.9 megabits per second. Although it is difficult to predict

the display system requirements at this time, we have assumed it will be quite similar to the acquisition requirements since some images acquired will never be reviewed and others will be reviewed at multiple times.

Table 5 shows the equipment required for the network. Please keep in mind that this equipment list is for radiology only and does not include display systems in other parts of the hospital. The 88 video monitors indicated are grouped four per station, each station associated with one display CRT. The four digitizing CRT's and pen-readers are to be attached to the digitizing DeAnza. Within one to two months,we will be using a DEC PDP 11/40 as the communicator, but this will ultimately be replaced by a more specialized networking device. The imaging system is a DEC VAX 11/780 which is about to move to our research laboratory. Currently only the digital fluorographic system is using the fiber optic link and, therefore, this imaging network is by no means complete at this time.

The VAX is well suited for the role of the host processor in an image processing network. Its relatively fast cycle time insures that it will not be rate limiting in communications with the minis and micros comprising the rest of the network. For the "number-crunching" required for image analysis, the virtual architecture and 4-gigabyte address space of the VAX is ideal.

However, there are limitations which may arise with certain VAX configurations. To use a VAX in this application the memory size should

be at least twice the 1 megabyte minimum available. Image processing also requires large amounts of disk space. Another VAX problem is that the only terminal multiplexer now supported by the operating system generates an interrupt every character (both in and out), rather than interrupting on a buffered basis. This impediment to terminal communication (and unnecessary processor load) will hopefully be resolved by a technologically superior terminal multiplexer in the near future.

At the end of each fiber optic link in the network the following hardware is required:

Canoga CBE-100 bus extender ($2500)
Buffer and control board ($500)
Direct Memory Access (DMA) interface board

Approximate prices are in parentheses. The DMA board requirement will differ according to the processor. The LSI-11 micros require a DEC DRV-11B board ($1000), while the Unibus processors (PDP 11/34, VAX 11/780, etc.) require a DR11-W ($1600). Both DMA boards are parallel, 16-bit interfaces capable of megabaud transfer rates.

The costs indicated in Table 5 for these components are approximate, and are included only to give some estimate as to what the overall costs of such a system would be today. Obviously the cost for the jukebox optical disk is a wild guess but probably not far off. It is our firm belief that although such a system would cost over two million dollars

today, this system will probably be easy to configure for under a million dollars in the not-distant future.

The wideband coaxial system proposed as indicated in Figure 2 and Table 5 represents a composite of commercially available systems. The most versatile commercial system has a maximum number of video channels of 35 per cable while simultaneously carrying more than enough CRT's. In Figure 2, you will note that image buffers are located between the display system and the wideband coaxial interface. These image buffers consisting of 512x512x8 bits are connected to a digital-to-analog converter (DAC) as well as a modulator before being connected to the coaxial system. Each video monitor (88 contemplated) requires one image buffer although a properly designed overall system might require fewer image buffers than monitors since not all monitors would be needed simultaneously. Since one coaxial cable can only support 35 monitors, at least 3 cables are needed to cover the radiology department. The separate image buffers are absolutely necessary in order to simultaneously display multiple images.

The dedicated display system is needed in order to insure rapid updating of the image buffers from the associated Winchester disks. These disks on the display system will hold probably no more than one day's worth of images unless an optical disk can also be attached to this system economically.

The Radiology Management System which will be connected to the communicator through 9600 baud terminal lines is already connected to

the hospital information system communicator which in turn delivers reports to the floors as well as obtains admission/discharge/transfer (ADT) information for radiology. The image reconstruction system will perform sophisticated manipulation of images for clinical use such as three-dimensional display of computerized tomography or NMR images. Gabor Herman and his colleagues are responsible for this image reconstruction system which is a DeAnza image array processor associated with a PDP 11/34.

In designing this system, a wideband coaxial interface was considered along with the fiber optic approach. Fiber optics were chosen primarily because of the greater data transfer rates possible and the great distances that could be achieved without line drivers. Fiber optics also have extremely low bit error rates. The fiber optic cables we are using can handle 5 megabits per second although with our interfaces that data transfer rate is reduced to 3.2 megabits per second. Wideband coax, on the other hand, can handle up to 2.5 megabits per second in very dedicated environments. Actually the wideband coaxial approach may be slightly less expensive than the fiber optic approach if multiple paths are required. The interfaces for the fiber optic system are slightly more expensive than for the wideband coax but the cable costs for coax which are between $5-8 per foot far exceed the cost of the fiber optic cable of $1 per foot. The other factor to consider is that the wideband coaxial system is now commercially available but the fiber optic approach is not yet available for most common computer bus structures.

Details of our fiber optic system have been described previously. However, for the sake of completeness, we are using Canoga Data Systems CBE-100 Bus extenders that are connected to special interface boards built in our department which, in turn, are connected to DRV-11 and DR-11W interface boards on the DEC Q-bus and Unibus respectively.

Summary

The specifications and configuration for the proposed imaging network at the Hospital of the University of Pennsylvania have been presented. This system includes both fiber optic links and a wideband coaxial system. The ultimate system design depends on the availability of low-cost digital storage which will probably be laser optical disks. One significant assumption is that 525 line television is adequate for display with at least a 1024 resolution image that can be magnified so that the monitor resolution will match the image resolution. This approach assumes that initial interpretation of radiographs will not be performed on these display monitors and this portion of the system will only be used for review and comparison. Although currently far from complete, the presently installed components have demonstrated the feasibility and usefulness of this approach.

INTERACTIVE COMPUTER GRAPHICS TECHNIQUES FOR THREE-DIMENSIONAL MOTION ANALYSIS OF CORONARY CINEANGIOGRAMS

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ABSTRACT

We have developed techniques of interactive computer graphics to analyze calibrated biplane coronary cineangiograms. Through computer-assisted tracing of vessel bifurcation points, as seen in each of the two views, we produce accurate quantitative three-dimensional models of the motion of these points. Each point is described by its three-dimensional coordinates (typically within $\pm$.5mm) in each frame of the cineangiogram through one to four beats (typically 100 to 300 frames). We have modeled the motions of 10 to 40 points on the left anterior descending and circumflex arteries and their branches in 20 films of human hearts. Standard techniques of computer graphics have been used to display the 3D data, e.g. a stereo "instant replay" of an animated image of the motion of the arterial tree, at a viewer-controlled rate, as seen from any perspective desired. Computed measures are displayed similarly, e.g. a stereo animation of the velocity, in which a vector displayed at each point on the arterial tree indicates instantaneous 3D direction and speed of motion. The sequence of point coordinates represents the 3D motion of the underlying heart wall and is further analyzed to produce a variety of measures including: local wall displacement, speed, and velocity; segment shortening; cross-correlation of segment

shortening in order to map the propagation of the mechanical contraction wave; regional and global averages of local measures; the computed time-dependent least-squares fit center of contraction of these points; etc. The same techniques are applicable to cineradiographic studies of markers implanted in dog and human hearts, providing an accurate model of the 3D motion of any such points.

INTRODUCTION

Radiological imaging methods produce vast amounts of data which must ultimately be reduced to clinical judgments. Conventionally this data is simply recorded on a passive medium such as film and is reduced to a clinical judgement when it is viewed and interpreted by a physician. As computers are applied to aid in imaging and interpretation, an immense range of new methods become possible for recording data, for presenting many alternative processed images based on this data, and for computing other derived measures, e.g. a segment shortening graph measured from an LV angiogram, or a cardiac ejection fraction presented as a single number.

We have developed computer-based interactive techniques for extracting three-dimensional data from biplane cineangiograms[1,2,3,4]. The output of the data entry portion of the system is a "model" of the motion of 10 to

40 vessel bifurcation points (or implanted markers), describing their position in three dimensions (3D) in each of several hundred frames. By comparison to the amount of data represented by the original angiographic films, this model is very much reduced. But it is still a rich and general-purpose representation of cardiac motion, which can be further reduced to produce a variety of more abstract measures, e.g. segment shortening percentage. In addition to the possibility of producing new clinical tools, these investigations should improve our understanding of cardiac motion dynamics and help to determine what kinds of motion data should be extracted from other imaging modalities such as gated nuclear medicine, real-time ultrasound, digital angiography or dynamic CT.

DATA ENTRY

The position of a point in three dimensions (3D) can be determined by measuring its projection in two or more 2D perspective views. Most biplane cineradiograhic studies provide 2D perspective views which are well suited for such measurements, requiring no alterations to the standard procedure other than a calibration of the equipment.

We have developed a convenient method for accurately determining the relationships of the x-ray sources and films[5]. At some time when the x-ray equipment is in the same position used in an exam, usually just after the

exam is completed, we radiograph a plexiglass cube in which pieces of lead shot have been embedded at known locations. When the films are being analyzed it is necessary only to measure in both views the projected 2D positions of six or more of the pieces of shot. From this the system calculates all necessary calibrations of the spatial relationships of the x-ray equipment and the computerized film analysis equipment. This is more convenient and much more reliable than directly measuring the positions of the equipment.

In order to measure the motion of a vessel bifurcation point or an implanted marker it is necessary to track its position in each of the two views of a biplane cineangiogram. Typically the analyst tracks the point through one hundred to three hundred film frames. To aid the analyst the system superimposes onto the film image an animated computer graphics image which is synchronized with the film. The film image is front-projected onto a large (110 x 120 cm) screen, and a specially-constructed projection CRT is used to overlay the graphics image directly on the film image. The projection CRT is driven by a vector graphics display generator, which produces an image composed of points and lines (not "raster" graphics) and can change the image in real-time[6]. As the film projector runs, the animated display changes in frame-by-frame synchrony with the film. The analyst uses a data tablet to move a cursor which appears

in the graphics overlay. The system is controlled by using the cursor to select control functions from a graphically displayed menu. Data is entered by positioning the cursor on the point being tracked in the film and advancing the film projector. Tracking rates of 1-2 frames per second are typical.

The graphics overlay is the basis of several kinds of intimate interaction between the system and the analyst. For example, any data which has been entered previously can be viewed superimposed on the film. This makes it convenient for the analyst to review his entries, edit any errant entries, and keep track of what remains to be done. Further, the graphics overlay makes it possible to use the 2D positions of a point entered in one view to aid in tracking the same point in the corresponding frames of a second view. A point in view 1 (Fig. 1) determines a line in 3D between that point and x-ray source 1. That line can be back-projected into view 2. When seen in view 2, the 3D point of interest is constrained to lie somewhere on the projection of that line. The overlay of this back-projected "auxiliary line" is very helpful to the analyst in the task of recognizing the proper correspondence of points in the two views (Fig. 2) and in the task of tracking the point in the second view.

The elementary data produced by the system describes

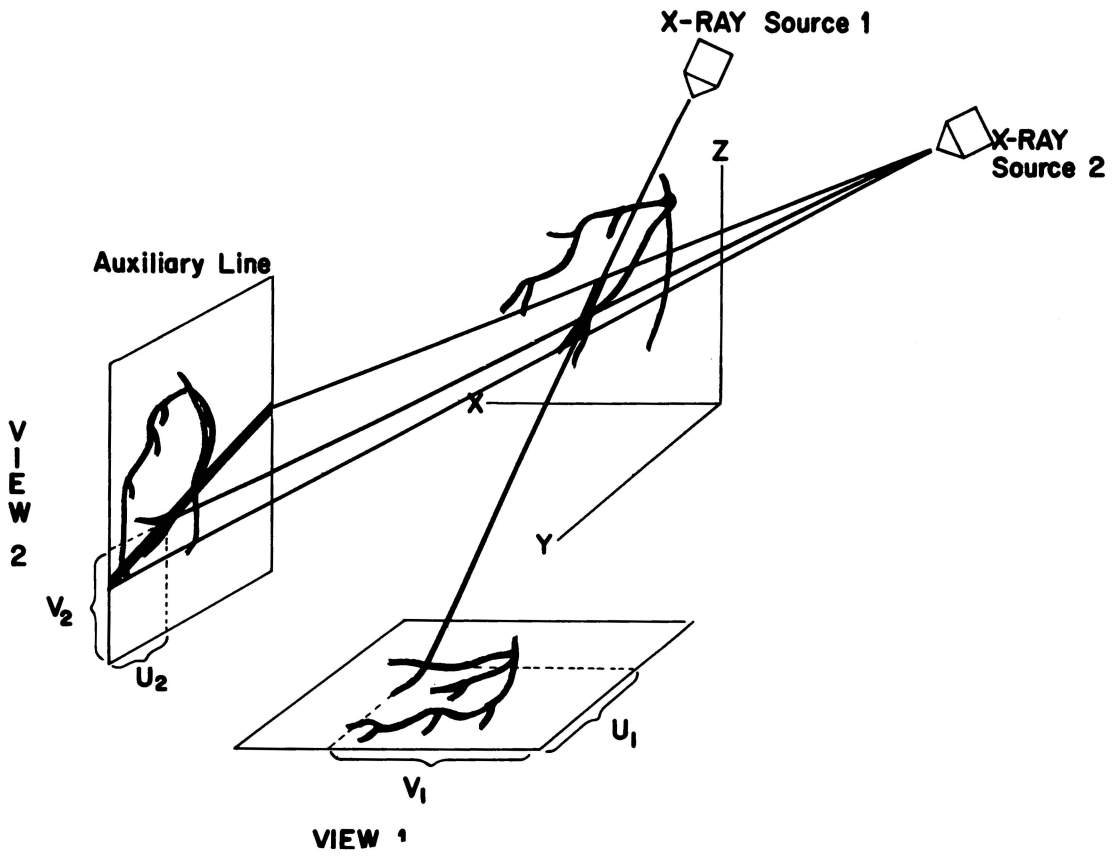


Fig. 1 Schematic of the relationship of the arterial tree being radiographed and the biplane views. The line between x-ray source 1 and a point in view 1 is projected into view 2.

the motion of points in 3D (Fig. 3). Each point is described for each frame T of the film by an X, Y, Z position and a measure E of the consistency of the least-squares reconstruction of the 3 coordinates (X, Y, Z) from the pair of 2D coordinates measured from the two 2D projections. In studies of vessels the limiting factor in accuracy is the ability to judge the center of a bifurcation "point". Studies of markers are accurate within $\pm$.5 mm.

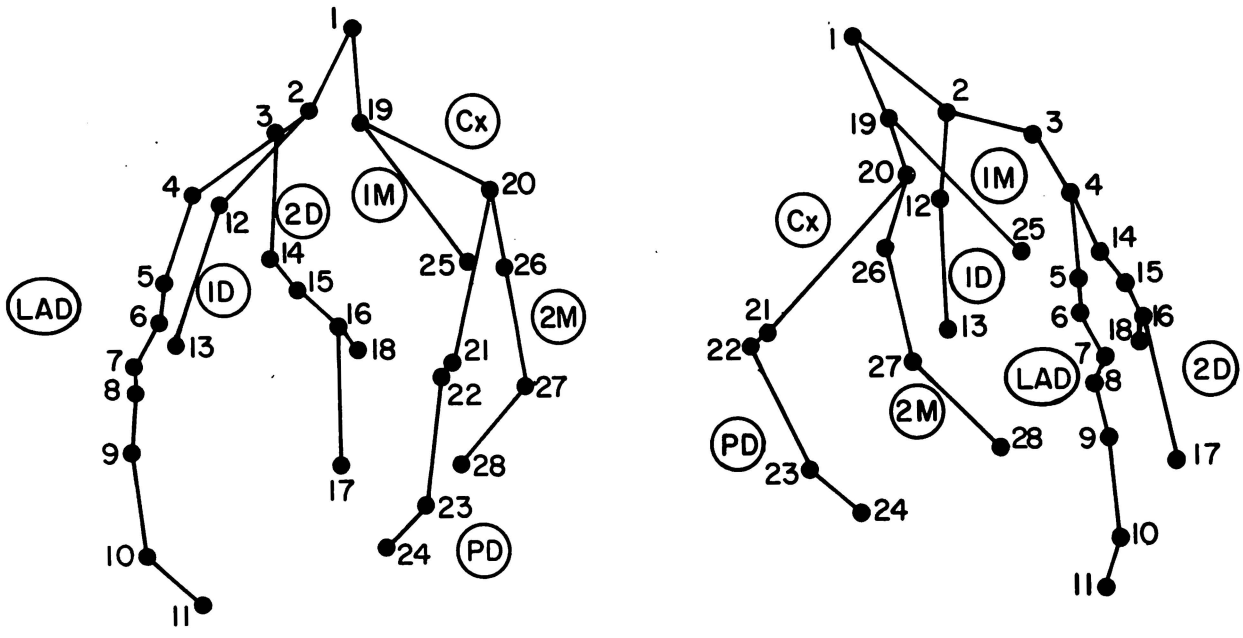


Fig. 2 Correspondence of bifurcation points on two views of a left coronary arterial tree. LAD - left anterior descending; 1D - first diagonal; 2D - second diagonal; Cx - circumflex; 1M - first marginal; 2M - second marginal; PD - posterior descending.

We have entered data describing the motion of from 10 to 40 bifurcation points in 20 cases. In some cases we have analyzed multiple injections, for a total of approximately 35 injections, through one to four beats, typically 100 to 300 frames per injection. Thus our model of the 3D motion of coronary bifurcation points is currently based on a total of: 35 injections * 25 points * 3 coordinates (X, Y, Z) * 200 frames, or approximately 500,000 computer represented values. In studies of the motion of markers implanted in dog hearts we have accumulated an additional 30,000 data

T	X	Y	Z	E
73	2.5155	.367001	1.51062	5.13013
74	2.41739	.491384	1.50103	6.4029
75	2.3173	.622377	1.48664	6.04749
76	2.24752	.719132	1.46835	5.12414
77	2.18825	.799004	1.45651	4.78363
78	2.11405	.867619	1.43536	5.29104
79	2.03872	.929565	1.38438	6.45804
80	1.96673	.971044	1.32162	5.79726
81	1.94226	.970156	1.24482	4.45804
82	1.95259	.939868	1.20434	2.55407
83	1.99325	.902285	1.19761	1.72477
84	2.05	.8483	1.24188	5.79536
85	2.09435	.753327	1.32991	8.3052
86	2.14781	.630126	1.42961	7.2675
87	2.19912	.524863	1.50626	5.1477
88	2.25465	.456682	1.54431	3.48692
89	2.29891	.412716	1.54947	3.78531
90	2.32531	.350728	1.55504	5.47362
91	2.34949	.278874	1.54195	6.54218
92	2.36768	.217599	1.52637	6.35734
93	2.39135	.183241	1.50711	2.50381
94	2.41258	.165777	1.50465	4.1723
95	2.44166	.181775	1.50975	3.31391
96	2.47075	.228417	1.51636	3.57321
97	2.50407	.276432	1.5191	1.16197
98	2.5198	.330807	1.51914	2.44608

Fig. 3 X,Y,Z coordinates (cm) for 26 frames of motion of a 3D point. E is an error measure for the least-squares reconstruction (digitizing tablet units).

values. The total is comparable to the amount of data in a few CT images. This is the elementary data from which a considerable variety of measures have been derived.

DERIVED MEASURES

The elementary data describing 3D point motions is the basis for many further calculations which summarize and

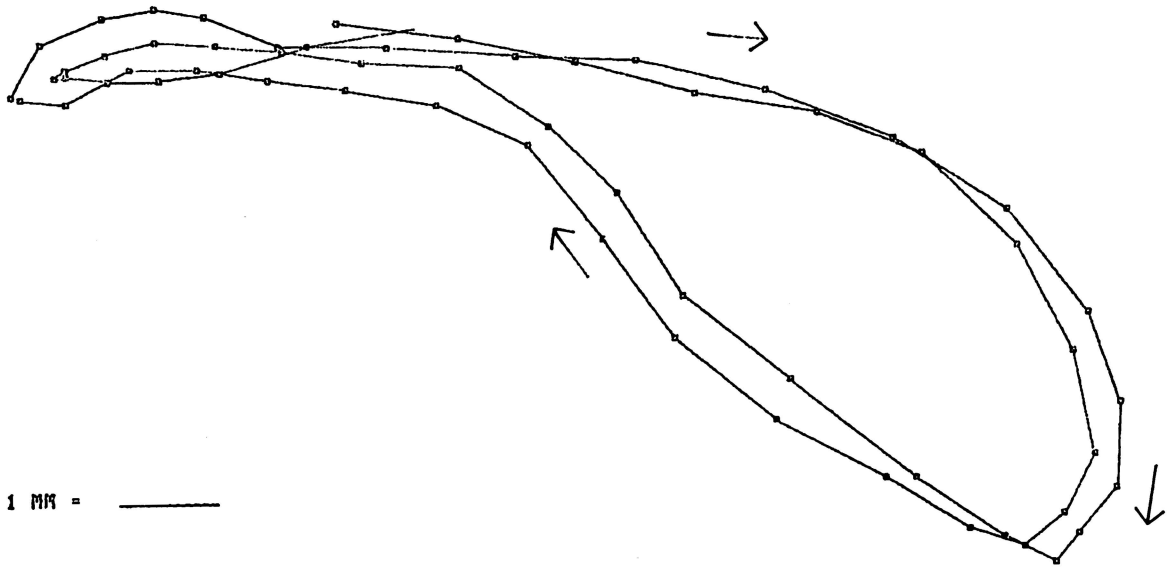


Fig. 4 Trace of a 3D point projected into a 2D view. Two beats are shown.

interpret it[7,8,9]. We list some of the measures which we have derived from the elementary data.

Because the elementary data is three-dimensional, it can be viewed from any perspective desired. Figure 4 shows the trace of a single point selected from the database, as it moves through two beats. Such a 2D view neglects motion in the direction perpendicular to the 2D plane and a viewing angle must be selected which is appropriate to avoid obscuring significant features of the motion. The viewing system allows convenient interaction in the choice of viewing angle in order to find an appropriate 2D presentation of the 3D motion. Further appreciation of the dynamics of the motion is gained if the display is animated,

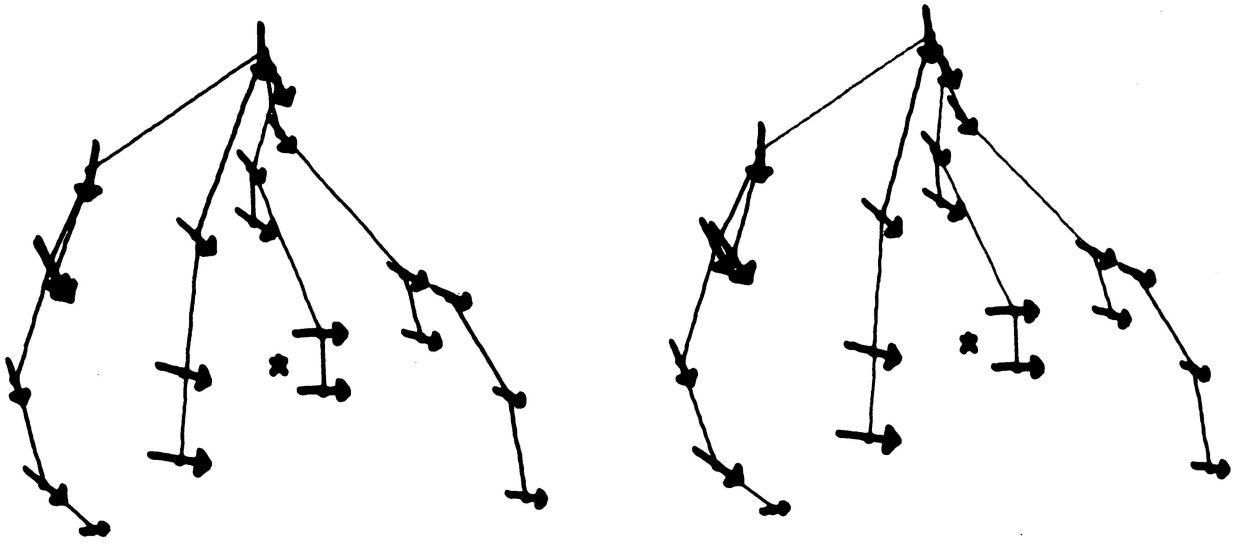


Fig. 5 View of an arterial tree with point velocity vectors in 3D. Asterisk is 3D computed center of contraction (COC) point.

thus indicating velocity, e.g. if the cumulative trace is displayed and a moving point is superimposed.

Of the various display devices for presenting animated and nonanimated 3D data the best are those based on the varifocal mirror principle[10]. Lacking such equipment we have generated animated sequences of stereo pairs of images, which can be displayed in real-time by our grahics display processor (DEC VT-11) and can be easily fused when seen through a stereo viewer which directs the two views separately to each eye. Stereo pairs do have the advantage that they can be reproduced in printed publications (Fig. 5). Most people can see such figures in stereo with the aid of a stereo

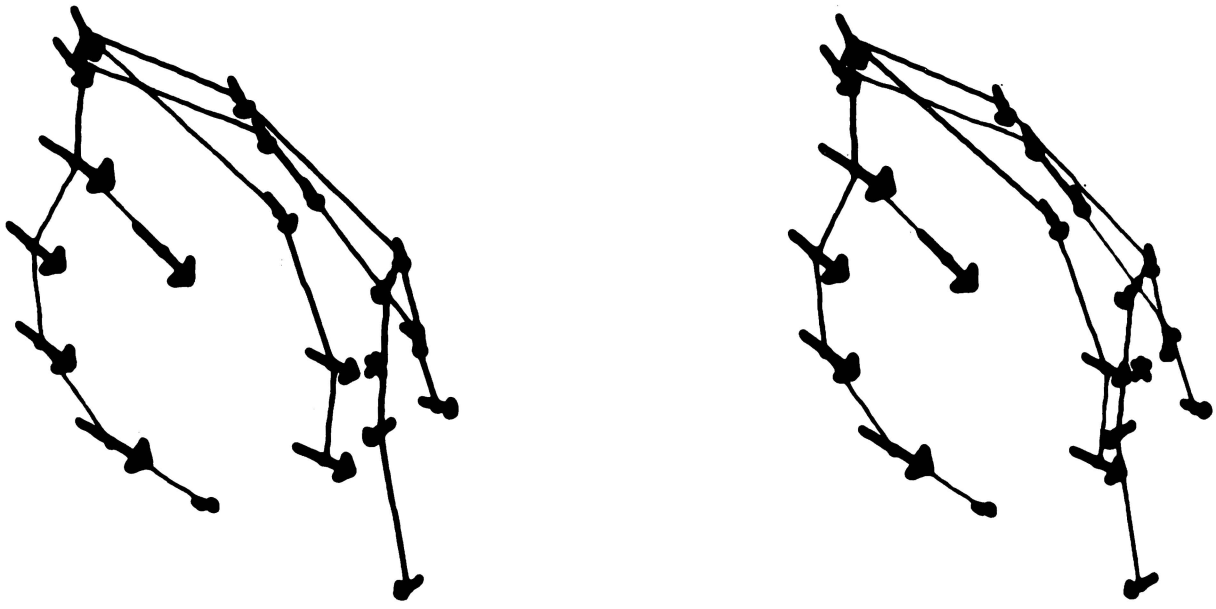


Fig. 6 Second view of same data as in Fig. 5; any such view can be chosen.

viewer; some patient or practiced people can fuse such images without a viewer. An animated sequence of these images not only displays the dynamic relationship of all the points but also enhances one's ability to fuse the two images into a perceived 3D object. We typically display only the data for one heart beat so the animation can cycle smoothly. A convenient rate control is provided since varying the rate reveals different aspects of the dynamics.

A natural way to view the relative motions of many bifurcation points is to add connecting lines which represent the vessels in the arterial tree. The connectivity information supplied by the lines also aids in identifying the points so that explicit labels (as in Fig. 2) can

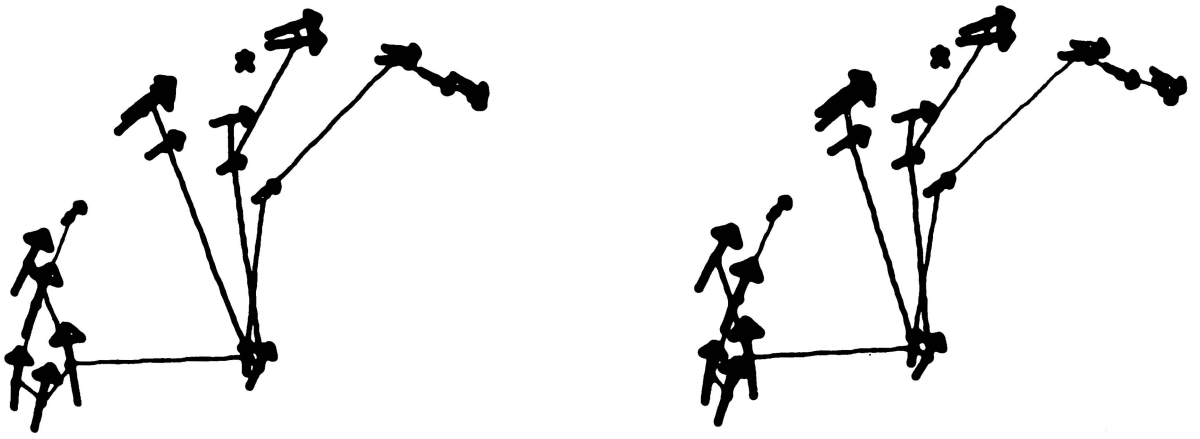


Fig. 7 Third view of same data as in Fig 5 and 6. View from base to apex shows substantial motion tangential to the heart wall.

usually be omitted (as in Fig. 5). Various measures derived from the point motions can be displayed near the points with which they are associated. For example, Figures 5, 6, and 7 include vectors which indicate the velocity in 3D of each of the points computed over a 7 frame wide moving interval.

The viewing perspectives can be chosen arbitrarily. Views common in radiography are often appropriate, e.g. LAO and RAO, and such views can be displayed whether or not they occurred in the angiogram from which the 3D model was produced. Figure 7 shows a view from base to apex, a view rarely seen in angiograms. This view is useful for observing the motion tangential to the heart wall.

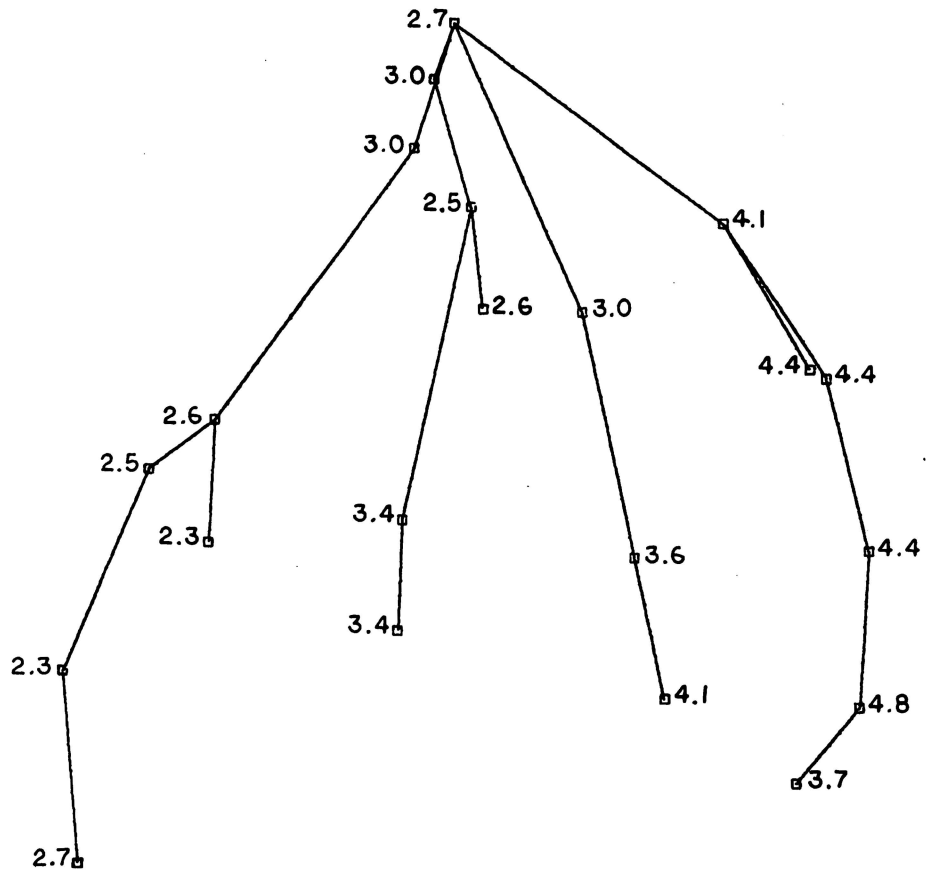


Fig. 8 Mean speed (cm/sec) of 3D points averaged over one beat and displayed in a particular 2D view.

Magnitude of Motion

Simple measures which do not change with time, such as mean speed (Fig. 8) or maximum 3D displacement, are conveniently summarized when displayed in relation to a static view of the arterial tree. Agreement among neighboring points is easily seen in such a representation. Broad regional variations are also apparent, such as the reduced motion of the anterior wall (lower left vessels in Fig. 8).

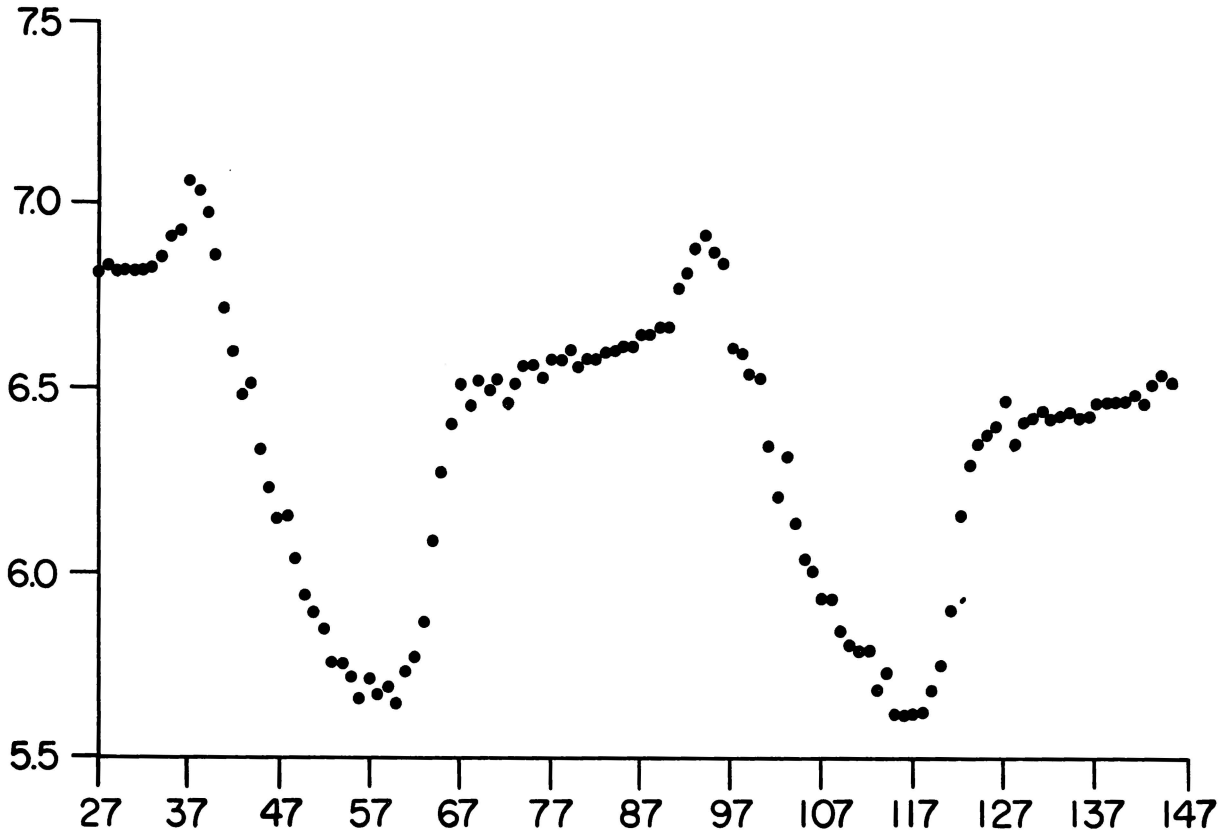


Fig. 9 Segment shortening graph, showing distance (cm) between two 3D points through 120 frames of motion.

Segment Shortening

A quantitative presentation of the relationship between points is provided by a segment shortening graph (Fig. 9), which is a plot versus time of the distance between two 3D points. Segment shortening graphs in 2D have become a standard method for quantitative evaluation in LV angiograms. Segments chosen along a vessel measure the local contractility of the wall, but segments defined from points on opposite sides of the ventricle or between points and the ventricular long axis or center of gravity are also of interest[11,12,13].

In typical graphs the time of minimum length is at end-systole. This minimum length is often maintained for several frames. Expansion begins abruptly and often contains the highest velocity motion. The plateau following expansion is diastasis, the period of slow filling of the ventricle. It is maintained for many frames in a heart beat with a long period but may nearly disappear in a heart beat with a short period. This effect accounts for most of the difference between graphs of long and short period beats. The plateau usually shows a slow increase in length followed by a peak at end-diastole which is associated with the atrial kick. The principal contraction of the ventricle begins sharply and eases into end-systole.

A further reduction of this data is obtained by computing percent shortening, which compares the lengths at end-diastole and end-systole and is defined as: 100 * (maximum distance - minimum distance) / (maximum distance). For our data typical percent shortening values are 10-40% depending upon where on the heart wall they are measured. Relationships of abnormal segment shortening graphs and reduced percent shortening to heart disease have been established previously[13].

Cross-correlation

The 3D data can be used to detect the mechanical wave of activity as it passes over the heart wall during contraction and expansion. The wave can be thought of as motion activity

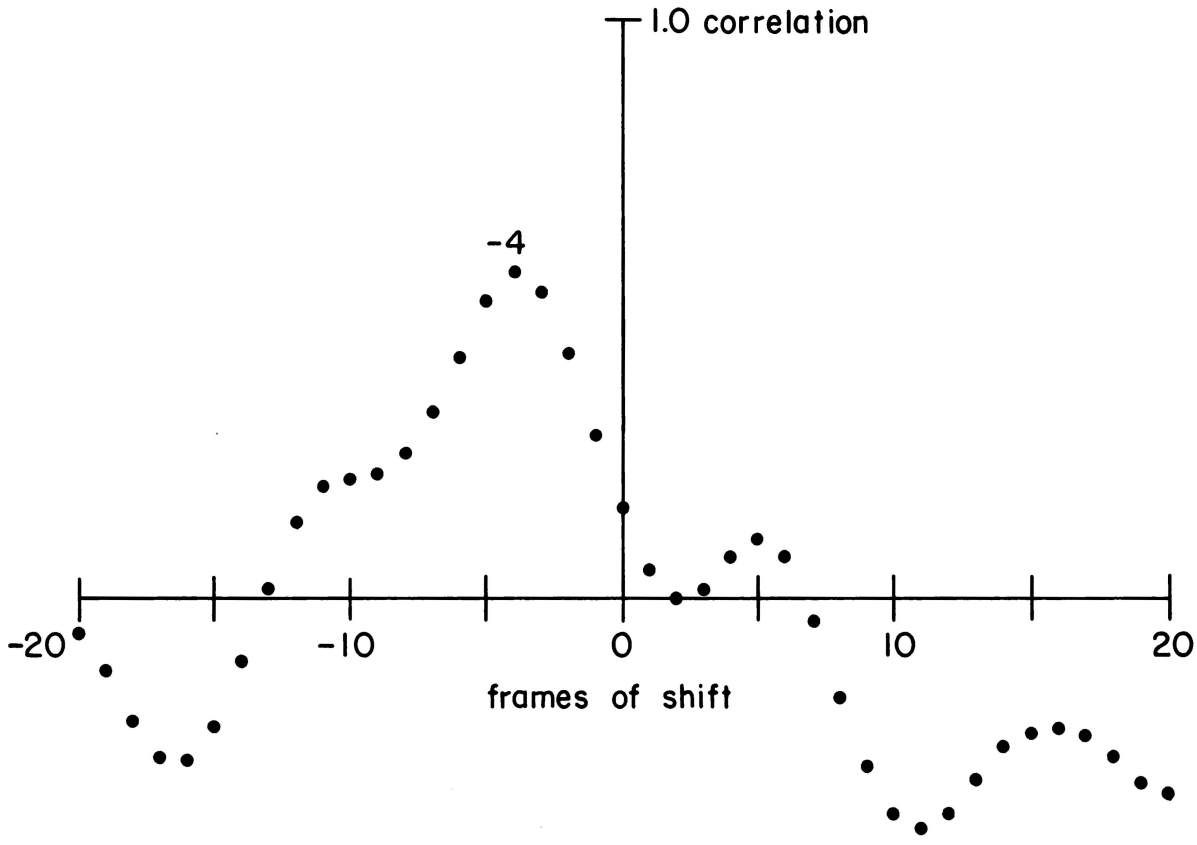


Fig. 10 Cross-correlation of the time series of two local activities, showing 4 frame (80 msec) phase shift.

that occurs first at one place on the wall and then a few frames later at another place on the wall. Measuring the time interval between these events permits us to construct a map of the relative times of these motion activities as they pass from region to region[8]. Cross-correlation (Fig. 10) of the time series of two segment shortening graphs can be used to determine the relative "phases" of similar activities in the two segments. Similarly the time series of the velocities of two 3D points can be cross-correlated. Fig. 10 shows a 4 frame interval (80

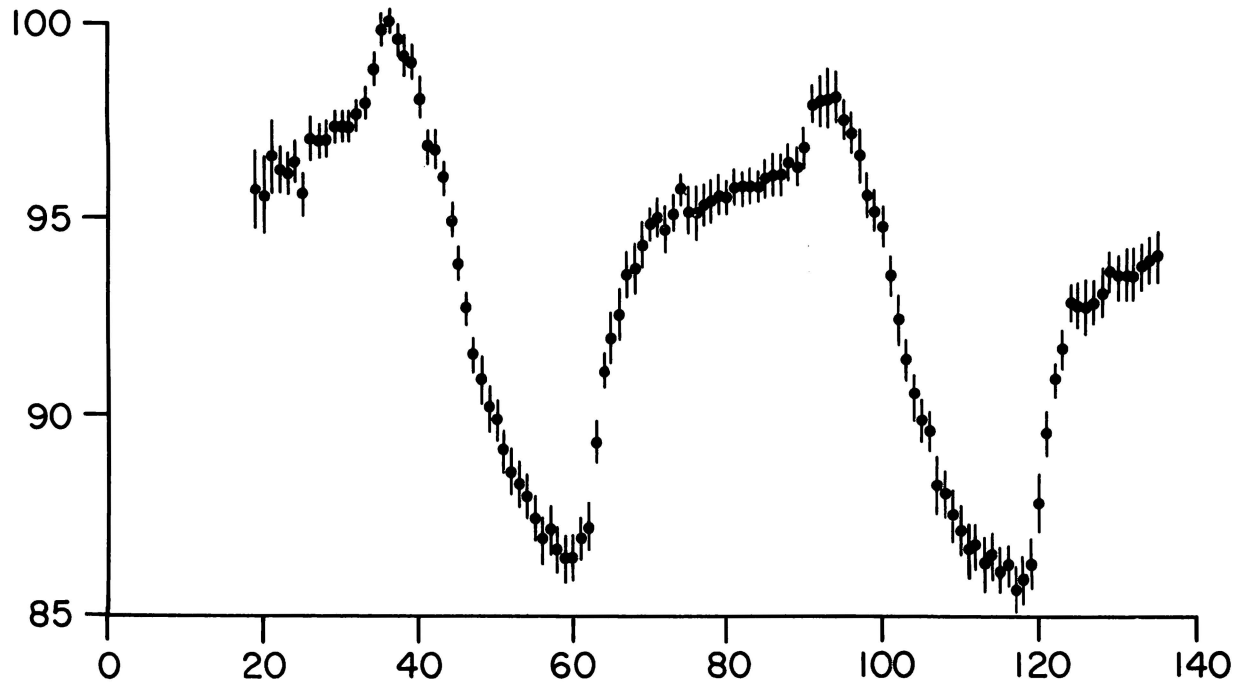


Fig. 11 Global segment shortening graph, showing percent shortening versus time (frames) for all points in a case.

msec) between the activities of a point on the LAD and a point on the first marginal.

Global Segment Shortening

A measure such as mean speed reduces the elementary data by collapsing the time domain to produce a single value. Similarly we can create aggregate measures by collapsing the identity of points, as in the single number which expresses the mean speed of all points combined or as in a global segment shortening graph, which combines all points but preserves the time domain. A global segment shortening graph (Figure 11) shows the average of all pairwise distances among 3D points as a function of time (frames). The bars indicate the standard error.

Normalized Time Periods

In order to combine or compare data from heart beats which have different periods, it is necessary to normalize the data with respect to time. The essential tool for this task is a program which recognizes end-systole and end-diastole times, typically from a global segment shortening graph (Figure 11). The elementary data are divided into beat periods and interpolated into a standard 50 time unit interval. Multiple injections within a case and within different cases are then comparable.

Spatial Normalization Techniques

The choice of spatial normalization techniques is a complex problem but is crucial to the proper use of the motion data which we are analyzing, and to any other analysis of heart motion. The elementary data provided by our system is described in a coordinate system external to the heart. Transferring this data to various other coordinate systems is central to the task of decomposing the motion into features which can be directly correlated with clinical questions.

In an investigation of alternative coordinate systems[9] our most interesting results stem from the concept of a computed center of contraction (COC) of the heart. Intuitivly, this is a point toward which all points on the wall move during contraction, and which they move away from



Fig. 12 Arterial tree with best fit lines. The dot is the best fit point (COC) at the convergence of the lines, which indicate the directions of motion on the individual points.

during expansion. A moving center of contraction is computed in each frame of the data as the 3D point which fits best, in a least-squares sense, to the intersection of the velocity vectors of all the points on the heart wall[8]. In Figure 12 the direction of the motion of the points is indicated by faint lines which tend to converge at a central point in the ventricle. This 3D point can be displayed as part of the animation of the motion of the arterial tree: the asterisks appearing in Figures 5,6, and 7 represent the position of the COC in those images. The COC exhibits its own characteristic motion[8,9]. Typically the COC moves between the region of the 40-50% point on a 3D midline of the ventricle, at end-systole and end-diastole, and the

80% point, close to the apex, at times of maximum systolic or diastolic motion. Hence its characteristic motion approximates two cycles up and down the midline for each heart beat.

Normalizations based on a moving center of contraction can be contrasted to the use of concepts of heart wall motion toward a midline representing the ventricular long axis or toward a stationary central point such as a ventricular center of gravity, which have been developed by numerous researchers for the analysis of left ventriculograms[13,14,15]. Our 3D data confirm the work of Ingels[14,15], which was based on 2D marker data, showing that the heart tends to contract toward a point rather than toward a line and that the center of contraction is a better estimate of this point than a center of gravity. The 3D data provided by our method is helpful in understanding the limitations and proper interpretation of 2D methods such as left ventrticulogram quantitation by conventional methods[14,15].

An interesting normalization, based on the COC, is achieved by projecting the 3D motion onto the line toward the COC and decomposing it into motion only along that line and motion perpendicular to that line[9]. Figure 13 shows the percent of the total motion of each point which is along the line connecting it to the moving COC. This data is for one case only but is typical of the results obtained in nine

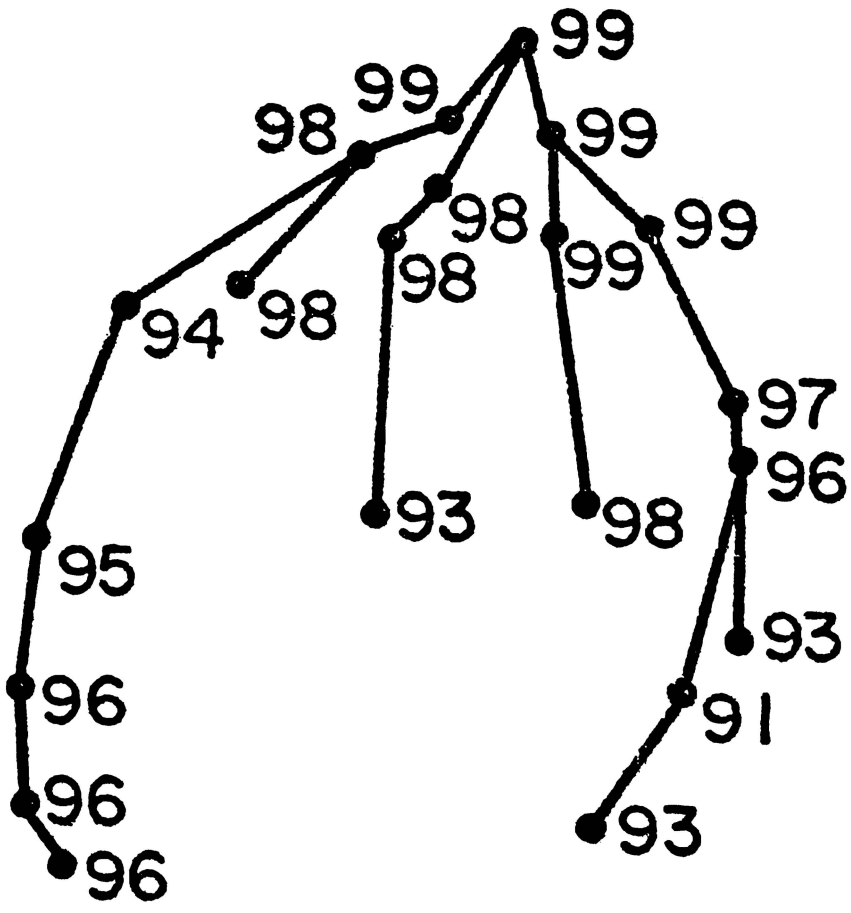


Fig. 13 Percentage of total motion which is toward the 3D COC, in a normal heart. The COC is computed in each frame; the percentages are averages through one beat.

cases in which subjects were examined because of chest pain but were found to have no coronary artery disease, mitral valve prolapse or abnormal wall motion as measured by LV angiography.

Local Abnormalities

A primary purpose of the spatial normalization techniques is to decompose the point motions so that local changes in the motion can be understood and related to local abnormalities.

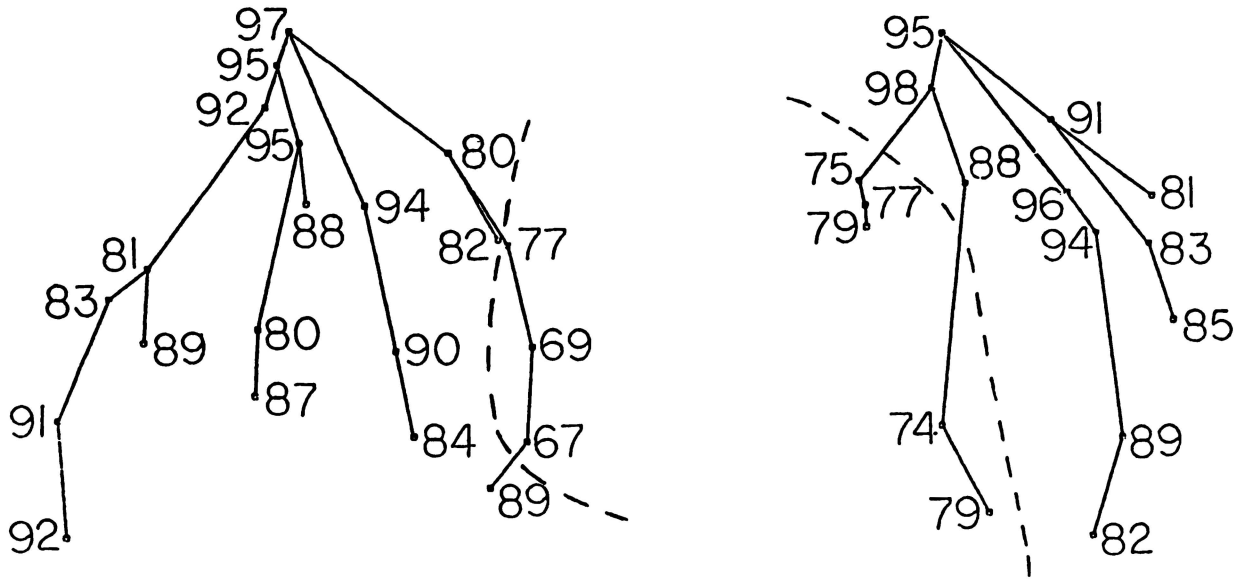


Fig. 14 Reduced percentage of total motion toward the COC, indicating dyskinesis. Two cases with local wall motion abnormalities.

Figure 14 shows the percent of the motion of each point which is directed toward the computed moving center of contraction. In each of the two cases shown, regional wall motion abnormalities were independently diagnosed by interpretation of films of biplane ventriculograms. Ventriculogram methods have come under criticism recently[13] as being prone to large quantitation errors and capable of missing local wall motion abnormalities. The diagnosed abnormalities appear to correspond to the regions indicated by the dashed lines where the percent motion toward the

COC is abnormally low. We are investigating whether altered 3D direction in local wall motion may provide a more sensitive indicator of local wall dysfunction.

Epicardial-Endocardial Correlations

The motion of implanted markers can be measured by the same data entry techniques used for bifurcation points. Because markers can be placed in controlled locations some additional measures become applicable.

Markers have been surgically implanted in dog hearts in pairs such that an epicardial marker is paired with a marker directly opposite on the endocardium. We have obtained data for 57 such pairs implanted in 14 dog hearts. A preliminary analysis of this data indicates that in speed and direction the epicardial and endocardial wall motion is highly correlated. As measured in a coordinate system external to the heart, the speed and the displacement of the markers in a pair have a correlation within the pair of 0.80 and are related by a simple linear factor, i.e. the mean epicardial speed is 73% of the mean endocardial speed and the mean epicardial displacement is 69% of the endocardial displacement. Treating this same data as time series and correlating the instantaneous speeds of the two markers yields a correlation coefficient of 0.75. The mean directions of the motions can be correlated by computing a best fit 3D

line for each of the points in a pair. For 57 pairs the average angle between the lines was 27 degrees (a correlation of 0.89). Fitting moving best fit 3D lines, based on 7 frame wide intervals, yields an average angle of 33 degrees (a correlation of 0.84) between the two instantaneous directions. Because the marker pairs have been placed systematically in five areas of the hearts (basal, anterior, lateral, posterior and apical) it is also possible to distinguish regional differences. The overall correlations described here held despite significant regional differences in mean speed (up to a factor of 2) and differences in mean speed between cases (up to a factor of 3). These overall correlations are a first step in clarifying the relationship of epicardial and endocardial motion and the extent to which each one can be predicted from measurements of the other.

DISCUSSION

Our methods are based on techniques of interactive computer graphics and require a human analyst to perform the rather tedious task of tracking points through several hundred frames of a film. This is a good compromise in a research-oriented system, allowing us to obtain data which is not otherwise available without undertaking to implement a system with automated tracking. Though we do burden the analyst/researcher with the basic tracking task, the system

has been made convenient to use through the provision of a good man-machine interface based on graphically-presented menues (no typing) and a graphic overlay of previously entered data[16,17]. Thus a variety of the analyst's interpretative skills are applied even in the process of producing the elementary data. For example, in the case that a bifurcation point being tracked is obscured by another vessel the analyst can use his understanding of the anatomy and of the motions of the contiguous vessels to help him judge the location of the obscured point. At a later stage of analysis other techniques of interactive computer graphics further involve the analyst by allowing him to view the previously entered data in a variety of ways. The ability to see the data presented graphically, and animated, is an important part of its further analysis. Thus the use of interactive graphics techniques extends from the initial entry of data into system through many further stages of analysis and interpretation.

An important advantage of this method is that the 3D data can be extracted from coronary angiograms which were produced for other purposes. Bifurcation points are visualized whenever a coronary angiogram is performed and hence can serve as the basis for the quantitative analysis of heart motion both before and after procedures such as bypass graft surgery or drug administration during cardiac catherization.

The analysis of the cardiac motions recorded in cineangiograms profits from computer-based methods for two primary reasons: (1) The analysis can be quantitative. Often quantitative methods are valuable for clinical purposes because they produce objective measures corresponding to useful but subjective "qualitative" methods. They are also important for research and in the generation of derived measures which require accuracy in the elementary data. (2) Computer-based methods make it possible to re-represent data based on the same physical measurements (in this case angiographic imaging) into many forms. Thus data can be transformed from a 2D analog recording on film, to a time series of 3D coordinates, to a graphic animation looking much like the original angiogram, to a few numbers summarizing statistics of the motion, etc. Quantitation and computer-based calculations are essential to our method of recovering 3D data from two 2D films. Three-dimensional data are important because the heart really does move in three dimensions.

ACKNOWLEDGEMENTS

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COMPUTERIZED MANAGEMENT STATISTICS ON A CT SCANNER

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The ability of computer information systems to produce useful management statistics for a Radiology Department is well documented (1). Unfortunately, many departments such as our own do not yet have computer information systems, so that needed statistics must be tabulated by hand from source documents or management decisions must be made in the absence of reliable data. The need for good data becomes acutely apparent when one attempts to justify the acquisition of new equipment, or to optimize the utilization of very expensive systems such as CT scanners. Our department recently installed a new Somatom 2 computerized tomography (CT) system, and we were confronted with the problems of deciding how many studies might be scheduled in a day, at what intervals they should be scheduled, how many hours the system should be operated, and how the charges for particular types of examinations should be set.

In order to help answer these questions we designed a manual record keeping system. The technologist performing the study maintained a log to record information about each case that was done. The data from these logs were tabulated by a member of the department's administrative staff to provide a weekly summary of CT activities. In addition, the logs provided data from which statistics such as average examination times for particular types of exams could be tabulated.

This system was not very satisfactory in several respects. The logs were not always accurately filled out by the technologists who were more concerned with caring for the patients and with operating the equipment to

produce optimal examinations than with writing out information which, for the most part, duplicated information they had to type into the computer to mark the films. As a result, it was necessary for administrative personnel to check the logs carefully each day so that they could correct obvious errors and supply missing data from the technologist's recollections or from other examination records. This required about thirty minutes a day, and tabulating a weekly summary occupied another four to six hours. This system was not very popular with anyone, although everyone agreed that the summaries were valuable.

We considered utilizing the record-keeping facilities provided with the Somatom 2 system to help gather statistics. As patients are scanned the system requires the technologist to type in the patient's name and identification number, and it allows the technologist to enter up to five lines of comments, each of which can contain up to 26 characters of text. The system automatically records some additional information for each patient. This includes the times at which the patient's first and last scans were done, the total number of scans performed for the patient, and the total mAs. These data are automatically stored on a disk file, and at the beginning of each day the Somatom 2 prints the contents of this file and then re-utilizes the same disk space for the next day's patients.

We considered employing the print-out of data provided instead of the manual worklogs for our record keeping system. However, the format of the print-out, unlike that of the log, was not convenient for tabulating data, and it appeared that we would have to copy the data from the print-out

to a manual form in order to tabulate it accurately. Furthermore, we were concerned about problems of data loss which might arise if one of the print-outs were lost or if the printer did not function properly (e.g. ran out of paper). Instead, we settled upon the idea of writing our own programs to extract the needed data from the Somatom disk file and to store the extracted data in a permanent file of our own. We could then write other programs to produce the desired listings, summaries, or statistics. We have implemented such a system and have operated it successfully for several weeks.

SYSTEM DESCRIPTION

The design and implementation of the record keeping system have been governed by several factors. First, we wished to capture and summarize more data than the Somatom 2 software was designed to handle. Second, we did not have access to the Somatom 2 software or documentation, and, therefore, we could not modify those programs in any respect. Third, we needed to minimize the amount of scanner time required for record keeping, as opposed to patient care. Finally, we wanted the system to be easily operated by CT technologists with little sophistication in computer systems.

The first step in operating the system is to capture patient data as examinations are performed. The additional data we capture include coded examination types, the time at which the study was scheduled, the length of exam time predicted by the radiologist who initially approved the examination, and the identity of the technologist who enters the data. This information is typed in the second comment line. Although

the first line would have been slightly easier to use, it tends to overlie the lower portion of the CT image if it is longer than three or four characters and if all five possible comment lines are filled in. Therefore, we restrict the amount of data in the first line to a single character denoting the patient's sex and two digits indicating the patient's age in years. The third through fifth comment lines contain variable amounts of data describing the study. The technologist code is included primarily to provide an audit trail in order to encourage accurate data input.

The use of a comment line to collect data is a ruse which violates the basic principal of system design that data fields should be used only for the purpose they were originally designed for. That is, comment fields should be used only for comments. It would be preferable to modify the Somatom 2 programs so that they would request each desired item of additional information, check its accuracy, and obtain any needed corrections from the technologist immediately, and store the information in a convenient format on the disk file. The vendor's reluctance to provide access to the source programs for this rather pedestrian portion of their system is probably not motivated by a desire to maintain secrecy. Instead the vendor is probably concerned about the need to enforce some uniformity among the many installed systems it must maintain. A compromise between the customer's desire to tailor a system to meet local needs and the vendor's desire to achieve uniformity might be possible if the vendor would design the system so that particular programs which accomplish simple tasks such as collecting patient data could be re-written by the customer. This kind of arrangement is used successfully in other types

of large programming systems, and would permit departments that have computer information systems to interface them directly to their CT systems. This, in turn, would allow the information system to supply patient data required to annotate the CT images automatically and would decrease the amount of technologist time spent typing. It would also make data such as scan times available to the information system which could then produce the desired management statistics.

In order to assure that the patient data stored by the Somatom 2 programs are saved before they are overwritten by the next day's patients, we have captalized on the fact that the Somatom 2 software runs under the RT-11 operating system. Normally the technologist begins the day's operations by initializing the operating system, entering the current date and time, and then typing the system command to run the Somatom 2 program, MS02. Using standard RT-11 utilities we re-named the Somatom 2 program, and wrote our own program named MS02. This program first checks the current system date against the date in the patient information file header. If the technologist has neglected to specify a current date for the operating system, he or she is instructed to do so. If the system date is the same as the date on the patient data file, the program simply turns control over to the Somatom 2 software and scanning may resume. This is done if the system has been shut down for repairs, has "crashed" and is being re-started, or is being re-activated to perform an emergency scan after normal hours of operation. As long as the current system date is the same as the date on the file, new patient data will be added at the end of the file rather than overwriting data previously stored

SOMATOM 2 SCANNER EVALUSKOP VIEWING SYSTEM

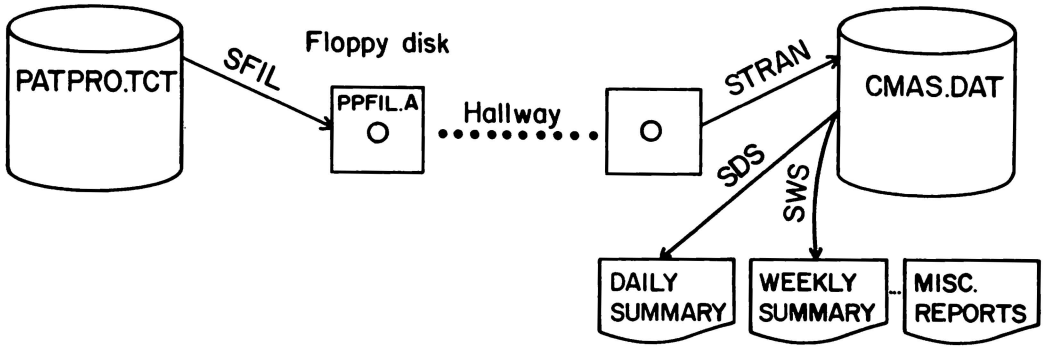


Figure 1. System Diagram

there. If the current date is greater than the date in the file, the program instructs the technologist to load a special floppy disk. After verifying that the proper disk is in place, the program copies the patient data from the Somatom 2 file, (PATPRO.TCT in Figure 1), onto the floppy (into file PPFIL.A) and also creates a backup of the file on the Somatom 2 system disk itself. The program then ask the technologist to remove the disk and initiates the Somatom 2 software so that scanning can begin. If the current date is more than one day greater than or is less than the date on the file, the program asks the technologist to verify or correct the current date before proceeding.

The next step in operating the system is to extract the desired data from the information stored on the floppy disk and to store the extracted data in a permanent file (Figure 1). This operation is performed at a convenient time by a supervisory technologist on our evaluation unit (Evaluskop), which is used routinely to run a variety of our own clinical and research programs (2,3) in addition to the Somatom 2

analysis routines. The transfer program, STRAN, instructs the technologist to mount the floppy disk and automatically checks and transmits all data from the "temporary" floppy disk file, to a larger, "permanent" file, CMAS.DAT, on one of our RL01 disks. If the program detects an error in the "additional" data in the second comment line, process, it displays all data recorded for the patient to the operator and requests entry of the correct information. The data displayed invariably contains enough information to correct the error unless the "patient" represents the scan of a test object or a "null" record which the Somatom 2 software generates under circumstances we do not completely understand. In these cases, the operator simply instructs the program to delete the record, and data transfer continues until all records on the floppy disk have been processed. Normally data is tranferred each day. However, the temporary floppy disk file has room for nine-hundred patient records so that several day's data can be held and transferred at a later time if this is convenient or necessitated by failure of the Evaluskop. In addition, the floppy disk file is handled as a nine hundred record ring buffer so that it provides some backup for the permanent file, which is also copied periodically as part of our routine operating procedure.

Summarizing patient data stored in the permanent file is quite strightforward. Currently, we have programs which produce daily and weekly summaries as well as a special report to compute examination time distributions. A sample daily summary is shown in Table 1. This represents a chronological listing of patients examined and is fairly self-explanatory. Note that the actual exam duration is computed as the time

TABLE I. Daily Summary

U. C. H. C --DEPARTMENT OF RADIOLOGY SOMATOM 2 ACTIVITY LISTING

	PATIENT NAME	PATIENT #	EXAM TYPE	# EXAMS	FIRST SCAN	LAST SCAN	EXAM DUR. (MIN)	# SCANS	TOTAL MAS	APPT TIME	DELAY	EST. DUR. (MIN)	ERROR IN EST. (MIN)	TECH CODE
-----	5-APR-82 -----													
1	[redacted] LOUISE	143-25-90-6	H	1	7:37	8:20	43	37	16640.	7:45	-8	45	-2	88
2	[redacted] [illegible]N	077-23-01-0	A	1	9:25	10: 1	36	58	13150.	8:45	40	45	-9	23
3	[redacted] HERMAN	162-29-87-4	A	1	10:23	10:51	28	64	14530.	9:30	53	45	-17	23
4	[redacted] KAREN	162-44-62-6	H	1	11:13	11:40	27	32	14340.	10:15	58	45	-18	88
5	[redacted] CAROL	118-50-58-3	AP	2	12: 9	12:20	11	28	6250.	11:15	54	45	-34	23
6	[redacted] [illegible]H	123-45-67-0	A	1	12:45	13:23	38	41	18630.	12:45	0	60	-22	85
7	[redacted] AARON	162-41-59-8	H	1	13:33	14:14	41	41	18100.	12: 0	93	60	-19	88
8	[redacted] [illegible]ANCES	149-00-44-3	C	1	14:45	14:54	9	21	4640.	13:45	60	45	-36	23
9	[redacted] EDDIE MAE	039-89-87-8	H	1	15:14	16: 5	51	56	22620.	14:30	44	60	-9	23
10	[redacted] DARLENE	054-89-67-9	AP	2	16:22	16:58	36	43	9700.	15:15	67	40	-4	63
11	[redacted] LOIS	162-46-63-9	H	1	17:29	18:. 5	36	47	19400.	16: 0	89	35	1	63
12	[redacted] CAROL	144-80-23-0	AP	2	18:26	18:52	26	39	8660.	16: 0	146	60	-34	63
13	[redacted] THEODORA	162-46-32-4	H	1	19:47	20:13	26	34	15260.	18: 0	107	35	-9	63
14	[redacted] FRANK	148-45-43-2	A	1	20:46	21:15	29	61	13840.	20:30	16	30	-1	85
15	[redacted] T	162-46-32-4	H	1	21:27	21:43	16	34	12730.	21:15	12	15	1	85
16	[redacted] RITA	145-99-55-9	SC	2	22:14	22:58	44	70	23350.	17: 0	314	60	-16	63
17	[redacted] M	157-37-64-	S	1	23:12	23:27	15	20	8900.	23: 0	12	20	-5	85
					TOTALS:		512	726	240740.		1157	745	-233	

AV. DELAY: 68 MIN
(1157 / 17)
AV. ERROR: -13 MIN
(-233 / 17)
PATIENTS 17

HEAD	7
SPINE	2
CHEST	2
ABDOMEN	7
PELVIS	3
EXTREM.	0
TOTAL # EXAMS	21

TOTAL OPEN TIME	950	MIN	=100%
EXAM TIME	512	MIN	= 53%
IDLE TIME	438	MIN	= 46%

between the first and last scan and therefore does not take into account the time required to move the patient in and out of the scanner. The average difference (AV. ERROR) of -13 minutes per study between the radiologist's estimated examination duration and the actual examination is quite reasonable when this is taken into account. A more serious operational problem is indicated by the delay between the time at which the exam was scheduled to begin and the time it actually began. On the day illustrated, this time averaged over an hour (68 minutes) per patient. A careful review of the day's activity shows that much of the delay resulted from starting the second patient forty minutes behind schedule. This delay propogated through subsequent studies. A second contributing problem indicated in the print-out is the difficulty our clerks have scheduling patients accurately with our manual scheduling system. For example, the tenth patient's examination was scheduled to begin only 45 minutes after the beginning of the ninth patient's 60 minute exam. Note also that exams for both the eleventh and twelfth patients were scheduled to begin at 4:00 P.M. Finally, the average patient delay was considerably increased by the five hour delay for the sixteenth patient, although it is likely that this patient was delayed at the request of, or at least with the agreement of, the patient's physician.

The overall room utilization times reported by the system must also be interpreted carefully. The total open time reported is arbitrarily computed as the time between the first and last clinical scans of the day. The total exam time is simply the sum of the individual exam times as defined above, and it does not include any time to "change" patients

TABLE II. Weekly Summary

SONATOM-2 WEEKLY ACTIVITY 4/ 5/82 -- 4/11/82.

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY	TOTAL	% OR AVERAGE
EXAM TYPE									
HEAD	7	7	6	6	7	5	2	40	44.0 %
SPINE	2	2	4	1	2	0	0	11	12.1 %
CHEST	2	1	1	0	1	1	0	6	6.6 %
ABDOMEN	7	2	6	6	5	0	0	26	28.6 %
PELVIS	3	1	1	2	0	0	0	7	7.7 %
EXTREM	0	0	0	0	1	0	0	1	1.1 %
TOTAL #	21	13	18	15	16	6	2	91	100.0%
# PATIENTS	17	11	18	13	15	6	2	82	
SCHEDULED	17	9	15	13	14	2	0	70	85.4 %
ERROR TIME	-233	-179	-247	-160	-144	-42	0	-1005	-12.3/PT.
WAIT TIME	1157	265	395	982	1120	39	0	3958	48.3/PT.
# SLICES	726	315	630	441	601	151	37	2901	31.9/EXAM
TOTAL MAS	240740.0	119560.0	190050.0	133980.0	207180.0	60240.0	16260.0	968010.0	11805.0/PT.
OPEN TIME	951	913	1027	885	1009	343	47	5175	
EXAM TIME	512	235	465	395	487	144	24	2262	43.7 %

TABLE III. Exam Durations

U. C. H. C. --DEPARTMENT OF RADIOLOGY SOMATOM 2 EXAM DURATIONS BY TYPE

EXAM DURATION (MINUTES)	EXAM TYPE: (PERCENTS ARE CUMULATIVE WITHIN EACH TYPE) HEAD	SPINE	CHEST	ABDOMEN	PELVIS	EXTREMITIES	TOTAL
1- 5	12= 14%	0= 0%	1= 25%	3= 8%	0= 0%	0= 0%	16
6- 10	6= 21%	4= 25%	1= 50%	5= 22%	0= 0%	0= 0%	16
11- 15	9= 32%	1= 31%	0= 50%	4= 34%	1=100%	0= 0%	15
16- 20	8= 42%	0= 31%	1= 75%	10= 62%	0=100%	0= 0%	19
21- 25	10= 54%	1= 37%	1=100%	6= 80%	0=100%	0= 0%	18
26- 30	10= 66%	2= 50%	0=100%	3= 88%	0=100%	0= 0%	15
31- 35	5= 72%	2= 62%	0=100%	3= 97%	0=100%	0= 0%	10
36- 40	9= 83%	2= 75%	0=100%	0= 97%	0=100%	0= 0%	11
41- 45	2= 85%	0= 75%	0=100%	1=100%	0=100%	0= 0%	3
46- 50	4= 90%	2= 87%	0=100%	0=100%	0=100%	0= 0%	6
51- 55	4= 95%	2=100%	0=100%	0=100%	0=100%	0= 0%	6
56- 60	2= 97%	0=100%	0=100%	0=100%	0=100%	0= 0%	2
61- 65	0= 97%	0=100%	0=100%	0=100%	0=100%	0= 0%	0
66- 70	1= 98%	0=100%	0=100%	0=100%	0=100%	0= 0%	1
71- 75	0= 98%	0=100%	0=100%	0=100%	0=100%	0= 0%	0
76- 80	1=100%	0=100%	0=100%	0=100%	0=100%	0= 0%	1
TOTAL #:	83	16	4	35	1	0	139
AVERAGE:	29.33	33.38	16.50	22.37	15.00	0.00	27.00
STD. DEV.	16.88	16.34	7.23	9.44	0.00	0.00	14.99

or any repair time. We keep separate records for system "down" time by hand.

The weekly summary illustrated in Table II is simply a recounting of the daily totals. The example shown demonstrates that the problem with patient delay discussed above for the daily summary was not an isolated problem. The zero delay and error times for the two examinations done on Sunday simply reflect the fact that both studies were unscheduled. For the week as a whole 85.4% of the examinations performed were scheduled. Table III provides a breakdown of examination times by exam type into five minute slots. During the month for which these statistics are computed a total of 376 examinations were performed, but 45 of these were done in conjunction with another CT study on the same patient. The

time statistics reflect only the patients who had single studies. The average times for the different types of examinations are quite similar--particularly when the relatively large standard deviations are taken into account.

CONCLUSIONS

We have been able to implement a simple record-keeping system which utilizes data entered by technologists as patients are scanned. We are using computer-generated summaries of these data to help identify and resolve problems in utilizing the scanner efficiently. The major problems we encountered implementing this system resulted from our lack of access to the source code and documentation for the data collection programs supplied by the vendor. Although we have circumvented these difficulties, it would be preferable to modify the programs so that they would prompt the technologist to input all required data, check its accuracy at the time it is entered, and store the data separately from the images. These objectives could be accomplished more easily if the vendor would modify the system so that it could invoke customer-written programs to perform these simple tasks.

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A COMPUTER SYSTEM TO MONITOR X-RAY EQUIPMENT PERFORMANCE

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INTRODUCTION

It is often difficult to obtain accurate data concerning equipment performance in most radiology departments. Equipment failures are commonplace, but accurate repair records are usually not maintained and the records that are kept are usually not suitable for prospective or retrospective analysis. In order to monitor equipment performance more carefully, a computer system has been developed and installed at the Mallinckrodt Institute of Radiology to gather accurate records concerning problems with every piece of x-ray equipment in the entire department. This system not only provides supervisors with a moment-to-moment picture of the status of each diagnostic room, but in addition it provides a well-documented record of equipment performance throughout the Institute.

MATERIALS AND METHODS

The programs to monitor x-ray equipment performance have been designed in a modular fashion, capable of running independently on their own computer system. Written in BASIC, they use the RSTS operating system on a PDP-11/34 computer system manufactured by Digital Equipment Corporation. Eight CRT terminals are provided in eight different diagnostic areas of the department

to gather information about problems with equipment. Information can then be displayed at over 20 terminals, located at key points throughout the department.

At the Mallinckrodt Institute, this application has been incorporated as one of the modules of the MIR computer information system, a system currently comprising a network of seven central processors and supporting over 125 computer terminals.

RESULTS

In March, 1981 a preliminary system for monitoring x-ray equipment performance was installed in the out-patient department. Within a few months, this system was incorporated in all the diagnostic areas of the department.

If a piece of x-ray equipment should fail, the floor supervisor indicates that fact to the computer by entering the time and the room where the failure occurred. A detailed list of the equipment components in that particular room is then displayed, and the supervisor indicates which component seems to be the source of the problem. At the same time, the maintenance department is notified (a group of full-time "in-house" employees).

Once the problem has been repaired, the maintenance engineer checks to see that the problem has been correctly entered into the computer, and that the time that the room is back in service has been correctly recorded.

EXAM ROOM STATUS
WEST PAVILION 10 03-Apr-82

	CURRENT STATUS:			TOTALS THIS YEAR:		
		Down time (hr:min)	Source of problem	Times down	Down time (hr:min)	% down time
ROOMS:						
1002 TOMOGRAPHY	OK			0		0.00
1028 MAMMOGRAPHY	OK			0	0:00	0.00
1029 GI STUDIES	OK			13	130:55	4.47
1032 GI STUDIES	DOWN	2:02	Fluoroscopic tube	5	14:57	.51
1033 GI STUDIES	OK			5	31:53	1.09
1036 BONE & JOINT	OK			10	11:09	.38
1037A NEURO	OK			0		0.00
1037B BONE & JOINT	OK			0		0.00
1038 CHEST	OK			7	41:03	1.40
1039 CHEST	OK			5	16:26	.56
1010A PROCESSOR	OK			0		0.00
1010B PROCESSOR	OK			0		0.00

Figure I - An example of the type of on-line CRT display which is available for each diagnostic area of the department.

Display terminals to monitor equipment performance are located throughout the department on each of the diagnostic floors and in key supervisory locations including the offices of the technical administrator and the director of the Institute. At any of these terminals it is possible to examine the current status of all of the rooms in any of the diagnostic areas of the department (Figure 1). If a room is closed for repair, the display indicates the nature and the duration of the problem. In addition, for each room there is an indication of the number of repair calls and the percentage of time that the room has been closed during the year. By reviewing these displays for each floor, a maintenance supervisor can quickly

** RADIOLOGY EXAM ROOM STATUS **

ROOM 1032 WEST PAVILION 10
G.I. STUDIES
ROOM UNIT: Manufacturer - Siemens
Model - Sireskop 3

ROOM TOTALS:

	Repair calls	Down time (hr:min)	% down time
This month:	1	2:02	3.45
This year:	5	14:57	.51

COMPONENTS:	CURRENT STATUS: (Date & time down)	YEAR'S TOTALS: Repair calls	% down time
1) Generator: Siemens Garantix 1000	OK	1	.37
2) Control panel: Siemens	OK	0	0.00
3) Radiographic tube: Siemens	OK	0	0.00
4) Tube collimator: Siemens Multileaf/Auto	OK	0	0.00
5) Radiographic tube stand: Siemens	OK	0	0.00
6) Fluoroscopic tube: Siemens	03-Apr-82 08:10	2	.07
7) Tube collimator: Siemens Multileaf/Auto	OK	0	0.00
8) Image intensifier: Siemens Explorator 3	OK	0	0.00
9) Spot film camera: Siemens 105mm	OK	1	.05
10) Table: Siemens Sireskop 3	OK	1	.02
11) Radiographic iontomat: Siemens	OK	0	0.00
12) Fluoroscopic iontomat: Siemens	OK	0	0.00

Figure II - Any one of the x-ray rooms in the department can be examined in detail. Here, information concerning one of the rooms listed in Figure I has been displayed.

survey the status of the entire department and determine which floors currently have equipment problems which warrant his attention.

In addition, from the display terminals it is possible to inquire in detail about any of the diagnostic rooms in the Institute (Figure 2). Once a room is selected, general information is provided describing the use of the room and the manufacturer of the equipment that it contains. A summary is provided concerning the number of repair calls and the total amount of time that the room has been

closed during the current month and the current year. In addition, a tabulation is provided for each of the major equipment components contained in that room. The current status of each component is indicated (if it is out-of-service, the date and time of the breakdown is displayed) and the number of repair calls and percent down-time is indicated for each of the individual components of the room. Thus it is possible to tell, when a specific component malfunctions in a room, whether that same component has caused problems earlier the same year. In rooms where breakdowns have been common, it is possible to document which components have been responsible for the problem.

Since each x-ray equipment component has been coded, it is possible to tabulate equipment performance throughout the radiology department. These tables summarize equipment performance categorized by manufacturer, equipment component, diagnostic area, and diagnostic room. The results can also be cross-tabulated with data on room utilization obtained in another program module of the patient information system.

DISCUSSION

The on-line monitoring of x-ray equipment performance provides some important incentives which can be useful in the technological management of the radiology department. In most departments there are already several pressures on the maintenance staff to work as quickly as possible, but the computer provides

an additional incentive by "advertising" the down-time for a piece of equipment throughout the Institute including the offices of the director and technical administrator.

The system also motivates the equipment manufacturer to see that his equipment stays in good repair. If a component in an x-ray room is causing frequent problems, that fact is recorded in the computer and then displayed for the rest of the year. Since terminals which display this information are located throughout the Institute, equipment problems are made known not only to members of the Institute but to visitors as well.

The accurate maintenance records provided by the computer have proved helpful to the maintenance staff in pinpointing recurrent problems and in ordering spare parts. This has been particularly true with complicated equipment such as CT scanners. The tabulations have also proved helpful in planning new equipment purchases. Radiologists often have "impressions" of room performance, but it is helpful to have these impressions confirmed by actual data. The "consumer's report" which is provided by the computer can, in selected cases, provide justification for choosing one equipment manufacturer over another.

CONCLUSION

A computer system to tabulate and display statistics concerning x-ray equipment performance provides technical administrators with a useful administrative tool. The widely distributed

on-line displays serve to motivate maintenance personnel and manufacturers alike to see that equipment stays in good repair. In addition, the carefully recorded data concerning the performance of every equipment component in the entire department provides a useful basis for establishing maintenance budgets, ordering spare parts, and planning new equipment purchases.

COMPUTER CALCULATED X-RAY TECHNIQUE

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ABSTRACT

A micro-computer based radiographic technique calculating system has been designed and implemented. By means of interactive menu selection and question and answer routines the system can obtain detailed information about a particular examination and calculate optimal technique factors. Use of the computer calculated x-ray technique factors is shown to reduce retake rates such that the system can more than pay for itself in the first year of operation.

INTRODUCTION

Obtaining consistently cost-beneficial and high quality images from radiographic procedures involving widely varying patient positions, and inherent contrast and thickness has been a continuing goal of diagnostic radiology. Technique charts, which have been a part of radiology since its inception, combined with the later addition of phototiming, have been the primary means of achieving this goal. The introduction of inexpensive micro-computers has recently allowed a further development; that of computer calculated x-ray technique (CCXT). A comparatively small program can, by interactively interrogating the radiologic technologist and calculating requisite technique factors, correctly handle a much more diverse range of examinations than possible by previous methods. Such a system not only has the potential for providing higher quality radiographs, but also providing lower patient dose and cost through reduced retake rates.

METHODS

The method used to calculate technique factors has been previously described (1,2) and hence will only be briefly reviewed. The inputs to the program consisted of the measured thickness of the subject part to be radio-

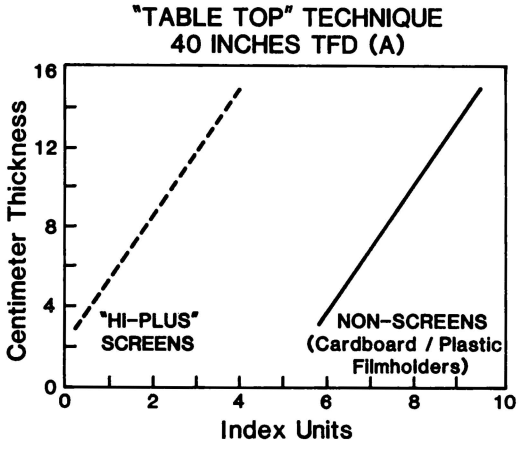


Fig 1 - Conversion graph for Table Top Technique

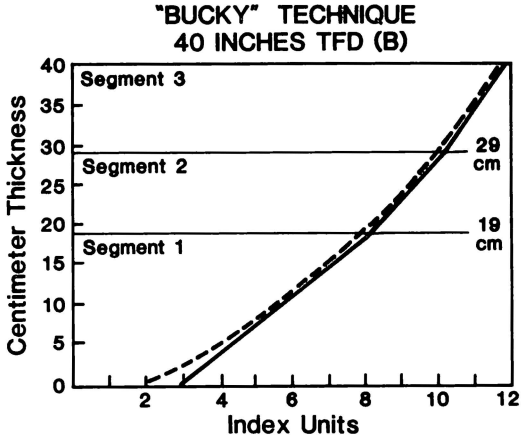


Fig 2 - Conversion graph for Bucky Techniques.
Note: The original relation between cm. thickness and index units is a curve which is treated as 3 tangents to the curve for calculation purposes.

graphed, together with answers to questions concerning the nature and intent of the examination. The x-ray exposure technique factors are calculated by a multi-step process. First a dimensionless logarithmic index number is derived from the part thickness, depending on which exam type is contemplated (Figs. 1-4). Second, this index number, after being subjected to additions and subtractions for the variables of the exam parameters (Fig. 5), is converted

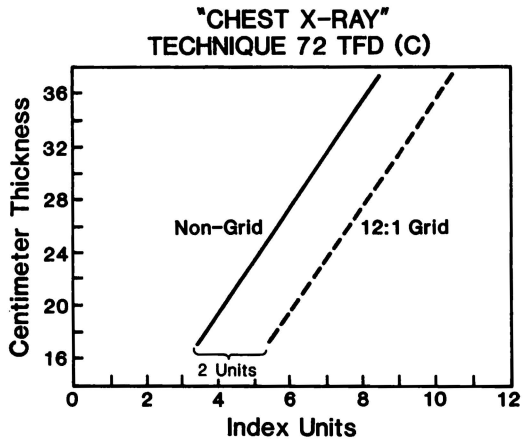


Fig 3 - Conversion graph for Chest X-ray Techniques.
Note: The technique is adjustable to any distance from the nominal 72".

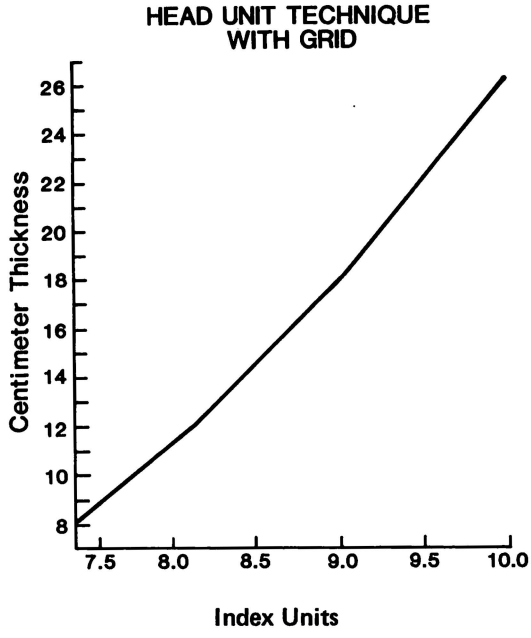


Fig 4 - Conversion graph for Head X-ray Techniques
Note: Omission of the grid subtracts 2.5 index units.

to a set of choices of kilovoltage, milliamperage and time settings (Fig. 6). (In case of "two control" equipment, it offers choices of kilovoltage and milliampere-seconds). All of this calculation is transparent to the technician, who is aware only of the series of questions on the CRT. The computer then offers

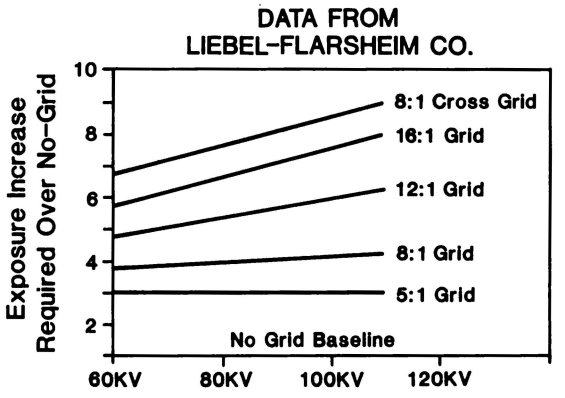


Fig 5 - Example of parameters which may modify number of index units.

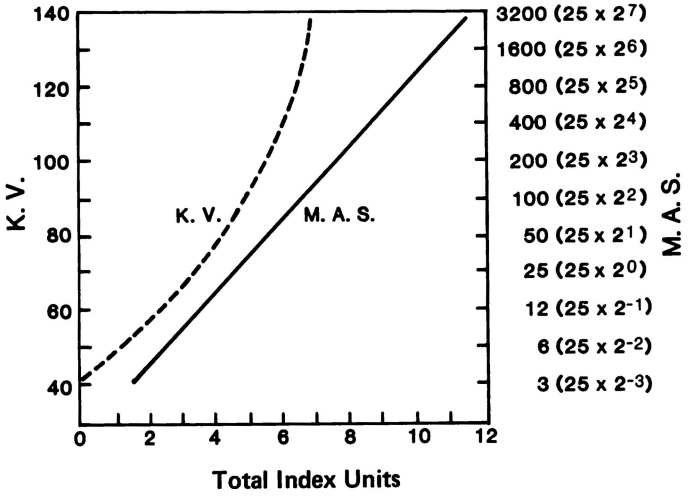


Fig 6 - Graph of relation of total index units to KV and MAS.

a suggested set of technique factors. If these are rejected, the kilovoltage or milliampere-seconds can be adjusted up or down until an acceptable set of values is obtained (based on the index number which was previously established).

At the start of the program, the technician is presented with the series of questions which prompt him to enter his initials, the patient's name and number, and the centimeter thickness of the part to be x-rayed, which must be measured by the technician using centimeter scale calipers. The next query

asks whether the exam will be Bucky, table top, chest board or Franklin head machine. If the response indicates a Bucky exam is intended, a menu of 10 types of examinations is displayed and the technician is asked to choose one or to make an additional entry. Subsequently, regardless of exam type, further questions are asked regarding certain variables as target-to-film distance, "coned down" field sizes and acceptability of an initially suggested kilovoltage. Depending on the exam type requested, various additional questions will be asked regarding the use of grids, angulation of the beam, use of cardboard cassettes, existing overlying plaster casts or other objects which may increase overall opacity. The technician may skip the next series of questions or answer them. They concern patient density factors and include items such as emphysema or pleural effusion in the case of chest x-rays, the presence of possible ascites in the abdomen, or the likelihood of severe osteoporosis in the osseous structures. A number of other clinical questions have been included at one time or another, but due to limitations of memory (4K bytes) only the essential questions could be retained.

The CCXT system as originally designed utilized a TRS-80 (Tandy Corporation registered trademark (Radio Shack)) micro-computer with 4K of memory to calculate x-ray techniques for over 95% of ordinary exposures (1,2). The only peripheral device was a cassette recorder. The total system cost was $400 in 1979.

In September 1981 the machine was updated to 16K memory (at a cost of $300) and it became possible to include many more questions, thus providing additional parameters to modify the examination. For example, an optimally exposed lateral view of the paranasal sinuses requires less exposure for a

given part thickness than a PA view, hence the computer requests this information if paranasal sinus examination is selected. Additional technique factors may also be incorporated, such as special densities for individual radiologists, adjustment for variations in x-ray machine output from one room to another, and also a quality control reporting program providing hardcopy output of exams performed and technical results obtained.

There is normally a 2 to 4 week interval required for training the technician in the utilization of the micro-computer. Part of the length of this training period is irreduceable due to the inherent learning curves of the technicians. However, it is felt that it could be partly reduced by improving the facility of the man-machine interface through more effective programming of the menus and decision logic. A number of different ways exist to prompt an uninformed user, and we are just beginning to learn how to improve the use of prompts for a group of x-ray technicians who have a widely varying educational background and socio-economic status.

RESULTS

Table I shows the variety of examinations which were successfully performed using the technique recommended by the micro-computer with minimal (4K) configuration. With the initiation of the expanded (16K) system, the number of available options was increased from 25 to over 900. For example, the system now incorporates consideration of the operating temperature of the X-Omat, so that overall system speed is continuously included as one of the factors in determination of recommended radiographic exposure settings. Any conceivable other variable desired can also be included easily if the modification occurs at a point in the calculations where the index value is

TABLE I

EXAMINATIONS PERFORMED USING
TRS MICROCOMPUTER WITH 4K RAM

A. Bucky exam

1. Lumbosacral spine and pelvis - 25
2. Ribs above diaphragm - 4
3. Ribs below diaphragm - 4
4. Cervical spine including 72" lateral erect - 5
5. Thoracic spine - 4
6. Bucky skull - 8
7. Bucky sinuses - 2
8. Upper GI series small bowel or barium enema - full of barium - 114
9. Postevac or full of Gastrografin - 56
10. Oral cholecystogram - 26
11. Miscellaneous other Bucky exams - 38

TOTAL 286

B. Chest exam

1. Chest, 72", with grid - 64
2. Chest, 72", without grid - 6

C. Table top exam

All extremities peripheral to shoulder joints and hip joints, any part thickness from 1 to 15 centimeters - 87

D. Franklin head unit

1. Skull - 43
2. Sinuses - 18
3. Facial bones and/or mandible - 12
4. Stenvers views, etc., for mastoids - 9

GRAND TOTAL 525

established. A 50% increase in exposure is obtained by addition of .5 to the index number, and a 100% decrease in exposure is achieved by subtracting 1.0 from the index number, etc. Additional modifications may include allowances for differences in x-ray output of different portable machines, variations in line voltage in different parts of the hospital when doing portable work, and almost any other variable may be included which may deleteriously affect the radiographic process.

Reports which show the technologist's initials, patient name and number, exam type and technique factor can easily be generated if this system is expanded to include a printer. At present this information is automatically recorded on a cassette using the tape recorder and printed out on another machine. A typical example is given in Table 2.

A summary of cost effectiveness is outlined in Table 3. It is evident that the micro-computer can easily pay for itself by reduction of wasted or spoiled x-ray film in the first year of operation in one "general purpose" x-ray room alone. Our previous experience (2) has shown that an average reduction of 15% in retake rates was initially achieved, but more recently, by maintaining the same technician in the room for more than four weeks, a reduction of 50% in retake rate has been possible.

Published reports indicate that 5-10% of the films exposed in any radiology department are wasted due to technical error (3-6). In some x-ray departments the amount of film wasted from this cause is unknown to the radiologist in charge. The technician immediately (and unobtrusively) repeats poorly exposed x-ray films. The radiologist who is not aware of this, often

TABLE 2

EXAMPLES OF REPORTS

1. JEC PT-WARREN RAY 342 16 18 70 EX-CHEST AP CM- 24 140KV300MA1/20SEC
2. JEC PT-WARREN RAY 342 16 18 70 EX-CHEST LAT CM- 28 115KV300MA1/5SEC
3. REPORT PT-WARREN RAY EX-CHEST AC2 RJO QUAL2K
4. JEC PT-GALVIN WENDELL 489 26 3251 EX-PA CHEST CM- 23 115KV300MA1/15 SEC
5. JEC PT-GALVIN WENDELL 489 26 3251 EX-LAT CHEST CM- 30 115KV300MA3/10 SEC
6. REPORT PT-GALVIN WENDELL EX-PA LAT CHEST AC2 RJO QUAL2L
7. JEC PT-LANGSTON DWIGHT 491 36 17 23 EX-SKULL SMV CM- 24 83KV300MA1SEC
8. JEC PT-LANGSTON DWIGHT 491 36 17 23 EX-SKULL LAT CM- 16 71KV300MA3/5SEC
9. JEC PT-BROWN GEORGE 500 18 00 51 EX-LATERAL CERVICAL SPINE CM- 12 83KV300MA2/5SEC
10. JEC PT-BROWN GEORGE 500 18 00 51 EX-CHEST AP CM- 17 71KV300MA1/30SEC
11. JEC PT-BROWN GEORGE 500 18 00 51 EX-CHEST LAT CM- 29 115KV300MA1/30SEC
12. JEC PT-BROWN GEORGE 500 18 00 51 EX-C SPINE AP CM- 14 71KV300MA1/5SEC
13. REPORT PT-LANGSTON DWIGHT EX-SKULL SMV & LAT AC2RJO QUAL2K
14. REPORT PT-BROWN GEORGE EX-C SPINE CHEST (AP&LAT) SHOULDER AC7 RJO QUAL7K
15. JEC PT-THOMAS LEROY 497 09 84 59 EX-KUB CM- 20 71KV300MA3/5SEC
16. JEC PT-LACY JOHNNIE 331 24 72 56 EX-CHEST AP CM- 20 115KV300MA1/20SEC
17. JEC PT-LACY JOHNNIE 331 24 72 56 EX-Y CM- 29 115KV300MA1/5SEC
18. JEC PT-BURNS JAMES E 488 01 91 43 EX-CHEST AP CM- 20 115KV300MA1/20SEC
19. JEC PT-BURNS JAMES E 488 01 91 43 EX-CHEST AP CM- 20 115KV300MA1/20SEC
20. JEC PT-BURNS JAMES E 488 01 91 43 EX-CHEST LAT CM- 29 115KV300MA1/5SEC
21. JEC PT-BRINKLEY DANIEL 495 28 42 74 EX-CHEST AP CM- 24 115KV300MA1/10SEC

TABLE 3

COST/BENEFIT RATIO OF CCXT

A. Cost of errors in x-ray technique/year

1. Single sheet 14" x 17" Kodak XRP film $2.18 (1.65 sq ft)

2. Chemicals used in processing $ .12

Total $2.30

(Estimate of film + processing = $1.39/sq ft)

(Labor and depreciation on equipment may add 50%)

Total estimated cost = $2.09/sq ft

B. Annual benefit from reduction in errors by 50%:

1. Cost of microcomputer $700.00

2. Annual cost per room (U.S. average x-ray room) based on 5,000 exams and 7% initial error rate:
Spoilage: 1,155 sq ft x $2.09/sq ft = $2,403.50
Benefit at 50% reduction about $1,200.00

3. Cost/benefit ratio (1st year) = $.58 cost/$1.00 benefit

assumes that his technicians seldom, if ever, produce a poorly exposed film and thus accurate information regarding the waste of film in a department is usually not known. The economic impact of such a loss can be considerable. In most 200 to 400 bed hospitals, a 10% waste of films will produce a loss of $10,000 to $20,000 per year, considering only the cost of film and chemicals. When the man-hours spent on repeat examinations are also included, the cost is at least 50% greater.

DISCUSSION

When operated consistently by a single technician for more than four

weeks, the use of CCXT has reduced our technical error rate 50%. In addition, it provides a written record of each examination performed in a given room, identification of the technician and technique, the number of views made, and the technician's appraisal of his own films. Such information can be useful in quality control and department management.

Presently under development is an interface between the micro-computer and the control panel of an x-ray machine. It will allow one of two paths to a more direct system control: a) a direct "report" from control panel to the computer, inputting the actual technique used, or b) the opposite approach, control of the x-ray generator by the micro-computer. Since digital circuits are common in control panels today, it should be possible to plug in the micro-computer to any of the newer x-ray machines. In the near future, most manufacturers will include micro-computers, many with technique generation capability, as an integral part of their radiographic systems. However, a large number of earlier generation systems will still exist which could benefit from the simple approach used here.

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COMPUTER BASED CENTRAL DICTATION AND VOICE MAIL

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Massachusetts General Hospital (MGH) Radiology continues to be interested in developing systems to improve radiology service. MGH has developed the film tracking, patient scheduling and reporting systems which have been previously described. The focus of this talk is on our recent efforts to provide access to consultations by referring clinicians as soon as possible via computer based central dictation and voice mail.

Traditional Process

A common sequence of events in the radiology interpretation process in academic departments is as follows:

1. Interpretation
2. Dictation
3. Transcription onto multipart form
4. Review and signature by resident
5. Corrections recycled to transcriptionist
6. Review and signature by staff
7. Rip and sort various copies
8. Distribute copies (chart, Radiology file, clinician, billing)

This process often spans 2 to 3 workdays or even longer. Location and retrieval of reports as the process unfolds is virtually impossible and at best is very time consuming. When

an in-process report cannot be located, the films are pulled and reread for the inquirer. The interruption and delays these calls produce are, unfortunately, well known.

Computer Based Transcription

The advent of the MGH computer based reporting system in 1978 has significantly improved the response time for clinicians. Transcription is performed using an in-house word processing system operating on a dedicated DEC 11/70 mainframe. Reports are available to residents and staff simultaneously for review and signature via the electronic mailboxes (video display terminals) scattered throughout the interpretation areas. Reports can be quickly displayed immediately after transcription. Radiology personnel are still required to read the results over the telephone, but search time is a fraction of the manual method previously discussed. Rereads are needed only for those reports not yet transcribed or with unusual findings. The process at MGH for reporting under computer control is as follows:

1. Interpretation
2. Dictation
3. Transcription via video display terminal
4. Review, signature and correction via video display terminal
5. Printing of computer presorted copies

6. Distribute copies

This process spans an average of one to two working days. Steps 4 and 5 are discussed in a separate paper.

Computer Based Dictation

The most recent development in accessing interpretation more quickly is the use of computer based dictation and voice mail. "Voice mail," "voice messaging" and "voice store and forward messaging," are all new terms used to describe a new technology. Similar to electronic mail's use of computers to store and transmit typed messages, voice mail utilizes computers to convert spoken words into digital signals, thus allowing computer control. Those signals can be written onto computer storage media (i.e., disks) for subsequent retrieval, reconversion and playback of selected reports via a telephone. This new technology allows the referring clinician direct access by telephone to the radiologist's dictation. Thus, radiology personnel are no longer required to interface with telephone inquirers and the need to relocate or reread films is virtually eliminated. The span of time from dictation to availability of results is thus reduced to zero. The process may be described as follows:

1. Interpretation
2. Dictation using computer based voice mail system
3. Intrepretation available to clinicians and

transcriptionists by telephone

4. Transcription using computer based voice mail system
5. Review, signature, and correction using electronic mailbox (VDT)
6. Print computer presorted copies
7. Distribute various copies

At MGH, we have participated in the development of such a system in conjunction with Sudbury Systems, Inc. Sixteen months ago, we installed a computer based central dictation system which allows clinicians to access report dictations prior to transcription. We struggled with many system bugs following installation. It took almost a full six months before the advantages started to outweigh the downtime problems. Currently, the problems have dwindled down to one or two minor software items which we are confident will be solved.

System Operation

Our system is configured to allow simultaneous usage by 21 dictation stations, 12 transcription stations and one telephone access line.

When a radiologist wishes to dictate, he or she uses a dedicated dictation station which has controls on the handset for dictate, reverse, listen and some special controls that allow, with a push of a button, the instantaneous reversal to

the beginning of a report or the return to the last place dictated. In addition, an intercom hookup to the transcription center exists. To begin dictation, the patient's record number (seven digits at MGH) is entered on the touchtone pad. This action produces a dictate tone which is interrupted when the dictate button is engaged. At the completion of a report, the phone is "hung up" using the "*" button or returning the handset to the cradle. The dictation process is then repeated for the next report.

Transcription is possible in four modes:

1. In order of the oldest untranscribed report for the entire system
2. In order of the oldest untranscribed report for a given dictate station (or identified radiologist)
3. Untranscribed by patient unit number
4. Already transcribed by patient unit number

At MGH, the usual operating mode is by oldest untranscribed report for a given dictate station since exam request forms for completed dictations are collected by station.

Clinician access can be performed via any telephone in the hospital at any hour of the day. Dialing a specific extension readies the RTAS-DM computer which will then accept a patient unit number. The most recent report for that patient

is heard first, the next previous report available can be heard by dialing "0." Reports may also be accessed by dictate station or from off-campus locations using a touchtone phone.

Traffic reports as specified by MGH are a major benefit of the system. A list of reports available via the housekeeper video display terminal is as follows:

- Number of untranscribed reports, by dictation sequence
- Port status (in use, etc.)
- Dictations by station (user) I.D.
- Dictations by patient I.D.
- List of all dictations on system
- Dictation summary reports
- Transcription production reports
- Access summary reports

These reports can be displayed on the housekeeper terminal or printed.

Conclusion

In conclusion, many distinct advantages are evident using the RTAS-DM computer based central dictation and voice mail system. The immediate availability of reports after dictation is the major advantage. Fruitless searches for in-process reports and related rereads by radiologists are essentially eliminated. Some peripheral secretarial hours have

also been eliminated, since verbal results are available via RTAS-DM 24 hours a day. The quality of digital recording is noticeably better than tape media.

The traffic reports are valuable. Untyped reports can be quantified in terms of length and age. Secretarial productivity can be measured.

The primary disadvantage of this system is its higher cost when compared with typical central dictation equipment. However, we feel that the unique features of this technology outweigh the additional cost. In fact, expansion of the system within the department is planned for the near future.

ANALYSIS OF NON-CT IMAGES ON A CT DISPLAY SYSTEM

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Radiologists have employed many measurements to quantitate features in diagnostic images (1). Unfortunately, many of these measurements are rather time consuming to perform, and may require relatively extensive calculations, so that radiologists tend to "eyeball" the image and utilize a qualitative estimate of features which might be expressed more precisely in numeric form. Computer systems have an obvious potential to assist in the collection and analysis of quantitative data, and most larger radiology departments have at least one computer system used for CT, nuclear radiology, or radiation therapy treatment planning. We have used our CT display system to capture and analyze quantitative data from film images in two types of examinations. The first of these is our most common exam, the PA and lateral chest radiograph, which is processed to yield an estimate of total lung volume. The second study, which is also a very common one, is the pregnancy ultrasonogram which can provide ratios of fetal head to body size as a measure of fetal growth in utero.

Methods and Materials

To perform the needed film measurements and calculations on our CT display computer has required the addition of some special hardware devices as well as preparation of specially written computer programs. Hardware additions included a data tablet with cursor to input film data, and a printer-plotter to provide a permanent record of the outlines used in the calculations. These devices may require special interfaces to the computer used, and the computer itself may require some minimal upgrade to support the installation of specially written programs. We initially implemented the programs on an EMI independent viewing console, but after a few

months transferred them to a Somatom 2 "super" Evaluskop. The details of the hardware and software configurations are described below.

Data Tablet

The device we have employed for input of film data is a Talos Model BL660 Data Tablet. This has a translucent back-lighted surface measuring 60" x 44" on which film images can be mounted. The location of a point on a film is entered by positioning the cross-hairs of a cursor appropriately and depressing one of the ten adjacent function keys. Using an antenna mounted inside the cursor and wires under the tablet surface the data tablet can electronically determine the location of the cross hairs within .25 mm. The data tablet model we used contains microprocessors which enable the device to scale values and compute lengths and/or areas on its own and to output these values to a CRT. It can also be used as a serial device linked by any RS-232 interface to a general-purpose computer. On the EMI IVC we employed one port of a Custom Systems Model 221 dual RS-232 interface between the data tablet and the Data General Eclipse. On the Digital Equipment Corporation PDP 11/34 used by the Somatom 2 Evaluskop we employed one port of an eight-port DZ-11 serial multiplexor for the data tablet.

The Printronix P-300 is a medium speed output device which can generate alphanumeric characters in a wide range of print-types or can be used as a plotter, producing overlapping dots with centers spaced as closely as 0.35 mm. This device is not necessary for the calculation or reporting of results. We use it to print the outlines and points entered by the operator in the scale of the original film, and file these printed outlines as part of the patient's radiology record. Thus, if any question regarding the accuracy of data input should arise, the printed outlines can be superimposed directly

on the films to check for errors.

The total cost of the hardware additions to the Evaluskop was about $14,000. However, by using a smaller data tablet and less expensive interfaces this cost could be reduced to about $7,500. The cost of a printer-plotter could be eliminated either by displaying the outlines on the CT monitor where they could be photographed, by using the lower-quality Decwriter, or by sacrificing the luxury of hard-copy outlines completely. In this event, the total cost of hardware additions would reduce to about $1,500.

Computer Systems

The EMI IVC on which the measurements were initially implemented utilized a Data General Eclipse S-200 with 16K words of memory. To this system we added 6K words of memory to install a RDOS operating system which allowed us to write and execute programs.

The "super" Evaluskop purchased with our Somatom 2 was ordered in a non-standard configuration to support the development of a variety of clinical projects including the two described in this paper. The system comprises a Digital Equipment Corporation PDP 11/34 processor with 256K bytes of memory, a KK11 cache memory, an FP11 floating point processor, special reconstruction hardware including a BSP10 and an IPC 2, a BP2 console, two RX02 "floppy" disk drives, two RL01 disk drives, two RK07 disk drives, a TU45 magnetic tape drive, and an LA34 Decwriter IV. To this we added the DZ-11A and Rianda 1202 interfaces for the data tablet and the Printronix printer respectively. We utilize the RT 11-SJ (version 3-B) operating system for the programs described below.

Software

The programs have been written, for the most part, in fairly standard

FORTRAN, and the listings are extensively commented. To some extent these desirable attributes resulted from the recognition during development that the programs would probably have to be transferred to another computer system in the near future. This transition was in fact accomplished in a period of about two weeks after installation of the Evaluskop. The only significant change required was providing new assembler language subroutines to access the interfaces to the data tablet and printer/plotter.

Lung Volumes

The idea of utilizing chest radiographs to estimate lung volumes quantitatively dates back at least to 1933 (2). Many techniques have been described and are summarized by Barnhard *et al.* (3). Several methods have been shown to correlate well with physiologic measurement techniques, such as phethysmography (4,5), and at least one has been implemented on a computer (6). We have employed the method described by Barnhard (3) as modified by Glenn (6), with a few further modifications as described below. Basically Barnhard's method approximates the intrathoracic volume with the volume of five elliptical cylinders whose heights, and major and minor axis lengths are determined from lung outlines on PA and lateral chest radiographs. The volume of the heart is approximated by an elliptical cylindroid; the volumes of the regions lying below the hemidiaphragms are approximated by portions (one-eighths) of elliptical cylindroids; and these are subtracted from the total intrathoracic volume estimate. From this result estimates of the lung parenchyma and pulmonary blood volumes are subtracted to provide an estimate of the pulmonary gas volume.

Glenn modified this method in three respects. Recognizing that the outline of the lung apices on the lateral projection of the chest is often

difficult to determine unless the view is overexposed, Glenn's program modified the upper one-fifth of that outline so that the overall height of the lungs as measured from the level of the highest hemidiaphragm would equal that on the PA projection. Second, whereas Barnhard utilized a fixed value for the parenchymal volume, Glenn utilized an estimate based on body surface area which varies with the patient's height and weight according to data which was published after Barnhard's method. Third, Glenn utilized 25 elliptical cylinders to estimate the intrathoracic volume rather than the five employed by Barnhard. Our method utilizes as many truncated elliptical cones as there are data points entered by the operator to specify the lung outlines. The effect of this change should be negligible.

To utilize the system the operator types into the computer terminal the patient's name, hospital identif cation number, and the examination date, followed by the patient's height in inches or centimeters and weight in pounds or kilograms. The remaining data are all entered via the data tablet in response to requests displayed to the operator by the system on the display console. The operator places the PA projection of the chest on the data tablet and traces the lung outline beginning at the left lateral costophrenic angle, proceeding through the left apex to the right apex and down the lateral margin of the right lung ending at the right costophrenic angle. The highest points on the right and left hemidiaphragm are then entered. Next, the operator marks the midpoint of the base of the heart and the cardiac apex, thereby describing the PA projection of the cardiac axis. Finally, the operator enters the furthest extent of the left and right cardiac margins as measured along lines perpendicular to the projected cardiac axis.

On the lateral view the operator traces the lung outlines from the

posterior costophrenic angle up the posterior margin of the lungs through the apex and down the anterior lung outline. The highest point on either hemidiaphragm is then marked; and finally the margins of the heart furthest from the lateral projection of the cardiac axis are entered. The system then prints the outlines and points entered. Finally, the computer displays and/or prints the calculated volumes.

Fetal Measurements

The fetal measurements described below have been developed to assist in the diagnosis of intra-uterine growth retardation (7,8,9). Although the bi-parietal diameter is helpful in determining the degree of fetal maturity, its interpretation is problematic if the dates of the last menstrual period are uncertain. Furthermore, it appears that small-for-dates babies can be divided into two categories. In one group there is a symmetrical decrease in the size of all organs. In another group the body is wasted out of proportion to the brain presumably because the brain is protected against the growth retarding stimulus. The ratio of head to abdomen circumference as measured by fetal ultrasound has been reported (8,9) to distinguish reliably between these two types of small babies, and this distinction permits better management of the pregnancy.

The operator begins by typing the patient's name, unit number and examination date into the computer. Next, the head image is mounted on the surface of the data tablet and the operator enters a length corresponding to ten centimeters using one of the scales on the image. Then the operator traces the head outline by entering consecutive points. These two operations are repeated to provide a check against errors committed by the operator or the apparatus. The abdominal data are then entered in a

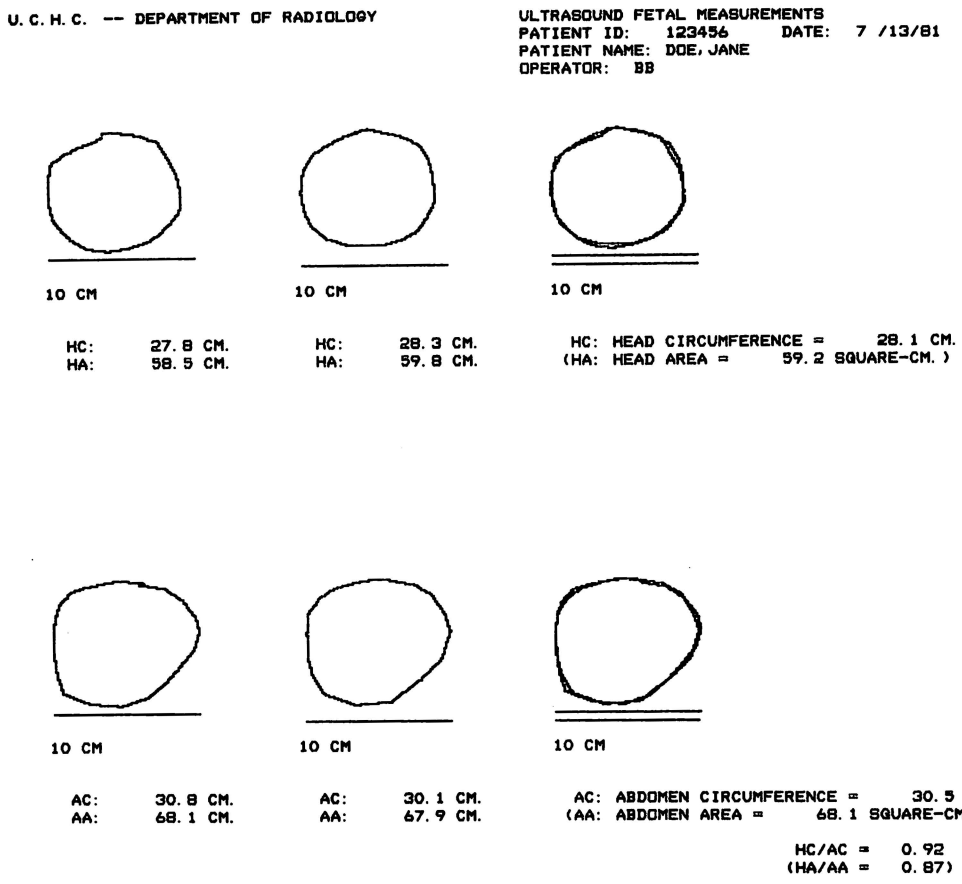


Fig. 1: Computer Output of the Fetal Measurement Program.

similar manner, and the computer prints out film-size copies of the scale marker and the fetal outlines along with the computed ratio (Fig. 1).

Discussion

The objective of these projects has been to provide useful measurements from non-CT images quickly, easily and accurately in a busy clinical department. The time required to process a chest radiograph for lung volumes is approximately five minutes, and that required for fetal measurements is about three minutes. The ease of operation is indicated by the large number of technologists and radiologists who have learned to operate the programs. A training session requires approximately 20 minutes for either program. The radiologist need not, however, interact with the system at all. He can quickly mark the necessary outlines directly on the films

with a wax pen and allow a technologist or even a clerk to input the data. In many instances a technologist can enter the data without any assistance from the radiologist. In either case the radiologist can superimpose the computer-printed outlines on the films to verify their accuracy before reporting the results.

The accuracy and clinical utility of these methods have been described in numerous articles. We have performed a few simple measurements to check for program errors. These have included correlation of the computer results with manual measurements and, in the instance of lung volumes, an informal comparison of the computer results with plethismographic and helium dilution methods in ten cases.

The ability to quantitate lung volumes from routine chest radiographs is considered quite useful by our cardiopulmonary radiologists in documenting the degree of suspected obstructive or restrictive lung disease. The physicians who operate the pulmonary function laboratory have been cooperative, perhaps in part because they see the radiographic method as a useful screening technique to identify patients who should undergo more extensive evaluation of their pulmonary physiology. The radiographic method is being applied in a retrospective study of a large series of patients to quantitate the loss of lung volume following radiation therapy to the thorax.

The fetal ultrasound measurements have also been quickly accepted into the department's operation. These measurements are now done routinely on all pregnancy ultrasound examinations by the technologist who performs the study. The results are reported by the supervising radiologist in each case. The data are being examined in conjunction with faculty from our obstetrics service to verify the clinical utility of the head-to-abdomen

circumference ratios and to compare this with the utility of cross-sectional area measurements. The overall effect has been to increase the cooperation between radiology's ultrasound section and the obstetrical service. The project has demonstrated that technology developed for one imaging modality can be used to enhance the diagnostic information obtained from another in a centralized department of clinical imaging.

Note: Copies of the source programs will be provided to any interested party in DEC RT11 format on either floppy disk or magnetic tape for a nominal fee to cover the costs of the recording medium, handling and mailing.

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